FOOD SCIENCE TEXT SERIES

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Essentials of Food Science

Third Edition

Springer

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OF FOOD SCIENCE

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PREFACE

It is with great pleasure that we introduce *Essentials of Food Science*, third edition. We hope that you find it more reader-friendly and more useful in explaining food science concepts.

Essentials of Food Science continues to be designed to present principles of food science with you, the nonmajor in mind: the Nutrition, Dietetics, Hospitality, and Culinary Arts student enrolled in an introductory Food Science course.

What is new: There are updates in each chapter, some significant. Additionally, considering the frequency with which terms are used on labels and in the press, a new Appendices section views biotechnology, functional foods, nutraceuticals, phytochemicals, and medical foods. To stay abreast of consumer concerns, the subjects of the USDA Food Pyramid and food label health claims are presented. As well, the Research Chefs Association certification is highlighted and a brief observation of human nutrigenomics is included. 'Culinary Alert!' appears throughout chapters in the text. Each Culinary Alert! is designed to point our culinary applications of the food science principle discussed.

The old expression "give credit where credit is due" is applicable to authorship! So... Thanks to the Lord for giving us grace to meet each challenge in the process of writing. We are appreciative of student queries and of those who provided materials used throughout *Essentials of Food Science* to offer better explanations of the text. Thanks to the Vaclavik and Christian families, our husbands and children.

More information is available in other texts relating to such topics as food chemistry, food engineering, food packaging, food preparation, food safety, food technology, nutrition and quantity foods, product evaluation, and in references cited at the end of each chapter. Bold, italicized words appearing in the text of each chapter are defined in a glossary at the completion of that chapter.

V. A. Vaclavik (vä -klä′ -vik̀)
E. W. Christian

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PART I

Introduction to Food Components

CHAPTER 1

Evaluation of Food Quality

Introduction

Food quality is an important concept because the food people choose depends largely on quality. Consumer preference is important to the food manufacturer, who wants to gain as wide a share of the market for the product as possible. Quality is difficult to define precisely, but it refers to the degree of excellence of a food and includes all the characteristics of a food that are significant and that make the food acceptable.

Whereas some attributes of a food, such as nutritional quality, can be measured by chemical analysis, food acceptability is not easy to measure as it is very subjective. In fact, consumers make subjective judgments using one or more of the five senses every time they select or eat any food. For example, potato chips, celery, and some cereals have a crunchy sound when they are eaten; the taste and smell of foods can be highly appealing or unacceptable; and the appearance and feel of a food also are important in determining its acceptability.

Food quality must be monitored on a regular day-to-day basis to ensure that a uniform product is produced and that it meets the required quality control standards. Companies also must monitor the quality of their products during storage, while changing ingredients and developing new lines. Objective tests using laboratory equipment are useful for routine quality control, but they cannot measure consumer preference. The only sure way to determine what a population thinks about any food is to ask them. This is done using sensory testing and asking panelists to taste a food and give their opinion on it. Both sensory and objective tests are important in evaluating food quality, and ideally they should correlate with or complement each other.

Engineers at food manufacturers are constantly developing new products both for “at-home” and eating-out markets. The intent is to better serve the customer’s needs and wants.

ASPECTS OF FOOD QUALITY

Food quality has both subjective and nonsubjective aspects. Appearance, texture, and flavor are largely subjective attributes, whereas nutritional and bacterial quality are not. The last two qualities can be measured objectively by chemical analysis, by measuring bacterial counts, or using other specific tests (1, 2). They will be mentioned only briefly in this chapter and the subjective qualities will be discussed in detail.

Appearance

The appearance of a food includes its size, shape, color, structure, transparency or turbidity, dullness or gloss, and degree of wholeness or damage. While selecting a food and judging its quality, a consumer takes these factors into account, as they are indeed an index of quality. For example, the *color* of a fruit indicates how ripe it is, and color also is an indication of strength (as in tea or coffee), degree of cooking, freshness, or spoilage (3, 4). Consumers expect foods to be of a certain color, and if they are not, it is judged to be a quality defect. The same is true for *size*, and one may choose large eggs over small ones, or large peaches over small ones for example.

Structure is important in baked goods. For example, bread should have many small holes uniformly spread throughout and not one large hole close to the top. *Turbidity* is important in beverages; for example, orange juice is supposed to be cloudy because it contains pulp, but white grape juice should be clear and without any sediment, which would indicate a quality defect.

Texture

Texture refers to those qualities of a food that can be felt with the fingers, tongue, palate, or teeth. Foods have different textures, such as crisp crackers or potato chips, crunchy celery, hard candy, tender steaks, chewy chocolate chip cookies, and creamy ice cream, to name but a few.

Texture also is an index of quality. The texture of a food can change as it is stored, for various reasons. If fruits or vegetables lose water during storage, they wilt or lose their turgor pressure, and a crisp apple becomes unacceptable and leathery on the outside. Bread can become hard and stale on storage. Products like ice cream can become gritty due to precipitation of lactose and growth of ice crystals if the freezer temperature is allowed to fluctuate, allowing thawing and refreezing.

Evaluation of texture involves measuring the response of a food when it is subjected to forces such as cutting, shearing, chewing, compressing, or stretching. Food texture depends on the rheological properties of the food (5). ***Rheology*** is defined as the science of deformation and flow of matter or, in other words, reaction of a food when a force is applied to it. Does it flow, bend, stretch, or break? From a sensory perspective, the texture of a food is evaluated when it is chewed. The teeth, tongue, and jaw exert a force on the food, and how easily it breaks or flows in the mouth determines whether it is perceived as hard, brittle, thick, runny, and so on. The term ***mouthfeel*** is a general term used to describe the textural properties of a food as perceived in the mouth.

Subjective measurement of texture gives an indirect evaluation of the *rheological* properties of a food. For example, a sensory panel might evaluate *viscosity* as the consistency or mouthfeel of a food. However, viscosity can be measured directly using a viscometer. Rheological properties therefore are discussed in more detail in section “Objective Evaluation” of this chapter.

Flavor

Flavor is a combination of taste and smell and is largely subjective. If a person has a cold, food usually seems to be tasteless. However, it is not the taste buds that are affected but the sense of smell. Taste is detected by the taste buds at the tip, sides, and back of the tongue, whereas aromas are detected by the olfactory epithelium in the upper part of the nasal cavity. For any food to have an aroma, it must be volatile, but volatile substances can be detected in very small amounts (vanillin can be detected at a concentration of 2×10^{-10} mg/liter of air). Aroma is a valuable index of quality. A food often will smell bad before it looks bad, and old meat can be easily detected by its smell. (However, foods that are contaminated with pathogens may have no off-odor, so the absence of bad smell is not a guarantee that the food, such as meat, is safe to eat.)

The taste of a food is a combination of five major tastes—salt, sweet, sour, bitter, and ***umami***. It is complex and hard to describe completely. *Sweet* and *salt* tastes are detected primarily on the tip of the tongue, and so they are detected quickly, whereas *bitter* tastes are detected mainly by taste buds at the back of the tongue. It takes longer to perceive a bitter taste and it lingers in the mouth; thus, bitter foods are often described as having an aftertaste. *Sour* tastes are mainly detected by the taste buds along the side of the tongue.

Sugars, alcohols, aldehydes, and certain amino acids taste sweet to varying degrees. Acids (such as vinegar, lemon juice, and the many organic acids present in fruits) contribute the sour taste, saltiness is due to salts, including sodium chloride, and bitter tastes are due to alkaloids such as caffeine, theobromine, quinine, and other bitter compounds.

Umami is a taste that recently has been added to the other four. It is a savory taste given by ingredients such as monosodium glutamate (MSG) and other flavor enhancers. The umami taste is significant in Japanese foods and in snack foods such as taco-flavored chips.

TASTE SENSITIVITY

People vary in their sensitivity to different tastes. Sensitivity depends on the length of time allowed to taste a substance. Sweet and salt tastes are detected quickly (in less than a second), because they are detected by taste buds on the tip of the tongue; in addition, they are usually very soluble compounds. Bitter compounds, on the other hand, may take a full second to be detected because they are detected at the back of the tongue. The taste may linger, producing a bitter aftertaste.

Sensitivity to a particular taste also depends on the concentration of the substance responsible for the taste. The ***threshold*** concentration is defined as the concentration required for identification of a particular substance. The threshold concentration may vary from person to person; some people are more sensitive to a particular taste than others and therefore are able to detect it at a lower concentration. Below the threshold concentration, a substance would not be identified but may affect the perception of another taste. For example, *subthreshold* salt levels *increase* perceived sweetness and *decrease* perceived acidity, whereas subthreshold sugar concentrations make a food taste *less* salty than it actually is. Although it is not clear why, flavor enhancers such as MSG also affect taste sensitivity by intensifying a particular taste in a food.

Temperature of a food also affects its flavor. Warm foods generally taste stronger and sweeter than cold foods. For example, melted ice cream tastes much sweeter than frozen ice cream. There are two reasons for the effects of temperature on flavor. The volatility of substances is increased at higher temperatures, and so they smell stronger. Taste bud receptivity also is an important factor. Taste buds are most receptive in the region between 68 and 86°F (20 and 30°C), and so tastes will be more intense in this temperature range.

Psychological factors also affect taste sensitivity and perception. Judgments about flavor are often influenced by preconceived ideas based on the appearance of the food or on previous experience with a similar food. For example, strawberry-flavored foods would be expected to be red. However, if colored green, because of the association of green foods with flavors such as lime, it would be difficult to identify the flavor as strawberry unless it was very strong. Color intensity also affects flavor perception. A stronger color may cause perception of a stronger flavor in a product, even if the stronger color is simply due to the addition of more food coloring. Texture also can be misleading. A thicker product may be perceived as tasting richer or stronger simply because it is thicker and not because the thickening agent affects the flavor of the food. Other psychological factors that may come into play when making judgments about the flavor of foods include time of day (for example, certain tastes are preferred at breakfast time), general sense of well-being, health, and previous reactions to a particular food or taste.

SENSORY EVALUATION

Sensory evaluation has been defined as a scientific method used to evoke, measure, analyze, and interpret those responses to products as perceived through the senses of sight, smell, touch, taste, and hearing (7). This definition has been accepted and endorsed by sensory evaluation committees within both the Institute of Food Technologists and the American Society for Testing and Materials. For more detailed information on sensory evaluation, the reader is referred to the books by Lawless and Heymann (8) and by Stone and Sidel (7).

Sensory testing utilizes one or more of the five senses to evaluate foods. *Taste panels*, comprising groups of people, taste specific food samples under controlled conditions and evaluate them in different ways depending on the particular sensory test being conducted. This is the *only* type of testing that can measure consumer preference and acceptability. When it comes to public opinion of a product, there is no substitute for tasting by individual consumers.

In addition to a taste-panel evaluation, objective tests can be established that correlate with sensory testing, which give an indication of consumer acceptability, but this may not always be sufficient. In the development of *new* foods or when changing an *existing* product, it is necessary to determine consumer acceptance directly and objective testing is not sufficient, even though it may be a reliable, objective indication of food quality.

Sensory methods may be used to determine:

1. whether foods differ in taste, odor, juiciness, tenderness, texture, and so on.
2. to what extent foods differ.
3. to ascertain consumer preferences and to determine whether a certain food is acceptable to a specific consumer group.

Three types of sensory testing are commonly used, each with a different goal. ***Discrimination or difference tests*** are designed to determine whether there is a difference between products; ***descriptive tests*** determine the extent of difference in specific sensory characteristics; and ***affective or acceptance/preference tests*** determine how well the products are liked or which products are preferred. There are important differences between these three types of tests. It is important to select the appropriate type of test so that the results obtained are able to answer the questions being asked about the products and are useful to the manufacturer or product developer.

The appropriate tests must be used under suitable conditions in order for results to be interpreted correctly. All testing must be carried out under controlled conditions, with controlled lighting, sound (no noise), and temperature to minimize distractions and other adverse psychological factors.

Sensory Testing Procedure

Sensory testing is carried out by members of a taste panel, preferably in individual testing booths under controlled conditions. All distractions, bias, and adverse psychological factors must be minimized so that the evaluation is truly an evaluation of the sample being tested and not a reaction to adverse circumstances, cultural prejudice, or the opinions of other testers. The noise level must be controlled to avoid distractions, temperature and humidity should be within an acceptable range, and lighting within the booth also must be monitored. In addition, there should be no extraneous smells, which may distract people from making judgments about the product under test.

Because color has a significant effect on subjective evaluation of a product, color differences may need to be masked. This is achieved by using red lights in the booths when necessary. It is important that people rate samples that may have different color intensities on *flavor* and not simply on the fact that they *look* different. For example, two brands of cheese puffs may look different because one is a deeper shade of orange than the other, and so one could tell the difference between them simply because of their color. However, there may not be a difference in the taste. If the color difference is masked by conducting the tests under red light, any differences detected could then be attributed to flavor differences and not to color differences.

The samples usually are placed on a tray and passed to each panelist through a hatch in front of the testing booth. The tray should contain a ***ballot*** that gives specific instructions on how to evaluate the samples and a place for the panelist's response. A cracker and water are provided, in order to cleanse the palate before tasting the samples. It is important that tasters have not eaten spicy or highly flavored food before tasting food samples or their judgment may be impaired. Preferably, panelists should not have eaten anything immediately prior to carrying out a taste test.

Additionally, it is important that panelists cannot identify the products they are tasting and that they do not know which sample is the same as their neighbor's sample, so that there is no room for bias in the results. This is accomplished by assigning three-digit random numbers to each product. For example, if two products are being tested (denoted product 1 and 2), each product is given at least two different random numbers. Panelists sitting next to each other will not be given samples with the same number, so that they cannot compare notes and agree with each other and introduce bias into the results that way.

If two products are being tested, 50% of the panelists must test product 1 first, and the rest must test product 2 first, but the order of testing must be randomized. This eliminates bias due to sample order and also due to any changes in experimental conditions that may occur from the beginning to the end of the test. The specific product order and random numbers seen by each panelist are detailed on a ***master sheet*** to ensure that the test design is carried out correctly.

Sensory Tests

Discrimination or difference tests are used to determine if there is a perceivable difference between products. Such tests would be used if a company was changing the source of one of its ingredients or substituting one ingredient for another. Difference tests also can be used to see if the quality of a product changes over time or to compare the shelf life of a particular product packaged in different packaging materials. For example, a difference test could be used to determine if juices keep their flavor better when stored in glass bottles rather than in plastic ones.

A *small* group of panelists may be used to conduct such tests and they may be trained to recognize and describe the differences likely to occur in the products being tested. For example, if trained panelists are testing different tea blends or flavor bases, they have more experience than an average consumer in recognizing

TEST #_________ **Panelist #_________**

TRIANGLE DIFFERENCE TEST

PRODUCT _________

INSTRUCTIONS: Proceed when you are ready. (Quietly so as not to distract others.)

FOR EACH SAMPLE:

1) Take a bite of the cracker and a sip of water to rinse your mouth.
2) Two of the samples are the same and one is different. **CIRCLE** the **ODD** sample. If you cannot tell, guess.

_________ _________ _________

3) Describe the reason why the ODD sample is DIFFERENT. (Please be specific.)

FIGURE 1.1 Ballot for triangle sensory test (obtained from Dr. Clay King at the Sensory Testing Laboratory at Texas Woman's University, Denton, Texas).

particular flavors associated with such products, are more sensitive to differences, and are able to describe them better. This partly is because they have been trained to identify such flavors. However, they are likely to be experienced tea drinkers (or tea connoisseurs) with a liking for different teas before they are trained for taste-panel work. Such people may be employees of the company doing the testing or members of a university research group. They would be expected to detect small differences in the product flavor that would go unnoticed by most of the general population. Thus, their evaluation would be important in trying to keep a tea blend constant or in determining if there is a significant flavor difference when the source of an ingredient is changed.

It also may be important to know if small differences in a product can be detected by untrained consumers, who simply like the product and use it on a regular basis. For this reason, difference tests often are conducted using larger panels of untrained panelists.

Two of the most frequently used difference tests are the triangle test and the duo–trio test. Typical ballots for these tests are given in Figures 1.1 and 1.2. These ballots and the one shown in Figure 1.3 were developed at the sensory evaluation laboratory at Texas Woman's University, Denton, Texas by Dr. Clay King, in conjunction with Coca-Cola Foods. The ballots have been used for consumer testing of beverages and other foods at the university sensory facility.

In the ***triangle test***, each panelist is given three samples, two of which are alike, and is asked to indicate the *odd* sample. The panelists are asked to taste the samples from left to right, cleansing their palate before each sample by taking a bite of cracker and a sip of water. Then they circle the number on the ballot sheet that corresponds to the sample they believe to be different. If they cannot tell, they must guess. Statistics are applied to the results to see if there is a significant difference among the products being tested. Because the panelists have to guess which is the odd one if they cannot detect a difference, one third of them

TEST #_________ **Panelist #_________**

DUO–TRIO DIFFERENCE TEST

PRODUCT _________

INSTRUCTIONS: Proceed when you are ready. (Quietly so as not to distract others.)

FOR EACH SAMPLE:

1) Take a bite of the cracker and a sip of water to rinse your mouth.

2) **CIRCLE** the number of the sample which is **THE SAME** as the reference R. If you cannot tell, guess.

R _________ _________

3) Why are R and the sample you chose the same?

FIGURE 1.2 Ballot for duo–trio sensory test (obtained from Dr. Clay King at the Sensory Testing Laboratory at Texas Woman's University, Denton, Texas).

TEST #_________ **Panelist #_________**

LIKEABILITY RATING AND PAIRED PREFERENCE TEST

PRODUCT _________

INSTRUCTIONS: Proceed when you are ready. (Quietly so as not to distract others.) Evaluate one sample at a time, working from top to bottom.

FOR EACH SAMPLE:

1) Take a bite of the cracker and a sip of water to rinse your mouth.

2) Taste the sample then CIRCLE the number which best expresses your opinion of the sample.

SAMPLE CODE:_________

Likeability	1	2	3	4	5	6	7	8	9
Scale	Dislike Extremely						Like Extremely		

SAMPLE CODE:_________

Likeability	1	2	3	4	5	6	7	8	9
Scale	Dislike Extremely						Like Extremely		

Describe the DIFFERENCES between the two samples. (Please be specific.)

Taste the samples again, then circle the one you prefer.

_________ _________

Describe the reasons why you prefer the one you chose.

FIGURE 1.3 Ballot for likeability and paired preference sensory tests (obtained from Dr. Clay King at the Sensory Testing Laboratory at Texas Woman's University, Denton, Texas).

would pick the correct sample as being odd just by guessing. Therefore, more than one third of the panelists must choose the correct answer for there to be a significant difference among the products. For example, if there are 60 members on a taste panel, 27 would need to choose the correct answer for the results to be significant at a probability level of 0.05 and 30 correct answers would be needed for significance at a probability level of 0.01. A probability level (or ***p* value**) of 0.05 means that out of 100 trials, the same result would be obtained 95 times, indicating 95% confidence that the result is valid. A probability of 0.01 is equivalent to 99% confidence in the significance of the results, because the same result would be expected in 99 out of 100 trials. Statistical tables are available to determine the number of correct answers required for significance at different probability levels (9).

In the ***duo–trio test***, each panelist is given a reference and two samples. He or she is asked to taste the reference first and then each sample, working from left to right, and circle on the ballot the sample that is the same as the reference. Again, if a panelist cannot tell which sample is the same as the reference, he or she must guess and statistics must be applied to the results to determine whether there is a significant difference among the products. If everyone guessed, 50% of the panelists would get the correct answer, and so for the results to be significant, more than 50% must choose the correct answer. For a panel of 60 people, 40 must give the correct answer for the results to be significant at the 0.01 probability level. Again, tables are available to determine if results are statistically significant (9).

Affective, acceptance, or ***preference*** tests are used to determine whether a specific consumer group likes or prefers a particular product. This is necessary for the development and marketing of new products, as no laboratory test can tell whether the public will accept a new product or not. A *large* number of panelists, representing the general public, must be used; thus, consumer testing is expensive and time-consuming. A relevant segment of the population needs to test the product. For example, if it is being aimed at over-50s, senior citizens must make up the taste panel and not mothers with young children. The opposite would apply if the product was aimed at young children. (Products aimed at children would have to be acceptable to mothers as well, because they would be the ones to buy it.) Ethnic products must be tested either by the group for which they are aimed or by a wide cross section of the public if the aim is to introduce the products to a broader market than is currently interested.

Panelists are not trained for this type of sensory testing. All that is required from them is that they give their opinion of the sample(s). However, they are normally screened to make sure that they are users or potential users of the product to be tested. Typically, they are asked to fill out a *screening sheet* and answer questions about how much they like the product (or similar products) and how often they consume it. Anyone who does not like the product is asked not to take the test. The screening sheet also may ask for demographic information, such as gender and age range of the panelists. The specific questions for each screening sheet are determined by whoever sets up the test, based on the consumer group they aim to target with their product.

The simplest preference tests are ***ranking tests***, where panelists are given two or more samples and asked to rank them in order of preference. In the *paired preference* test, panelists are given two samples and asked to circle the one they prefer. Often, the panelists are asked to taste a sample and score it on a nine-point hedonic scale from “dislike extremely” to “like extremely.” This type of test is called a ***likeability test***.

Sometimes panelists are asked to test more than one sample, to score each on the nine-point likeability scale, and then to describe the differences between the samples. This would not be a difference test, as differences in this case are usually obvious, and the point of the test is to see which product is preferred. In fact, the differences may be considerable. An example might be comparison of a chewy brand of chocolate chip cookies with a crunchy variety. The difference is obvious, but consumer preference is not obvious and would not be known without carrying out preference tests on the two products. A paired preference or ranking test may be included on a same ballot and carried out along with a likeability test. An example of a typical ballot is given in Figure 1.3.

Descriptive tests usually are carried out by a small group of highly trained panelists. They are specialized difference tests, where the panelists are not simply asked whether they can determine differences between the two products, but are asked to *rate* particular aspects of the flavor of a particular product on a scale. Flavor aspects vary depending on the type of product being studied. For example, flavor notes in tea may be bitter, smoky, and tangy, whereas flavor notes in yogurt may be acid, chalky, smooth, and sweet. A descriptive “flavor map” or profile of a product thus is developed. Any detectable changes in the product would result in changes in the flavor map. The training required to be able to detect, describe, and quantify subtle changes in specific flavor notes is extensive. Therefore, establishment of such panels is costly. When trained, the panelists function as analytical instruments and their evaluation of a product is not related to their like or dislike of it. The descriptive taste panel work is useful to research and development scientists, because it gives detailed information on the types of flavor differences between products.

OBJECTIVE EVALUATION

Objective evaluation of foods involves *instrumentation* and use of physical and chemical techniques to evaluate food quality. ***Objective testing*** uses equipment to evaluate food products instead of variable human sensory organs. Such tests of food quality are essential in the food industry, especially for routine quality control of food products.

An objective test measures one particular attribute of a food rather than the overall quality of the product. Therefore, it is important to choose an objective test for food quality that measures a key attribute of the product being tested. For example, orange juice is both acidic and sweet; thus, suitable objective tests for this product would be measurement of pH and measurement of sugar content. These tests would be of no value in determining the quality of a chocolate chip cookie. A suitable test for cookie quality might include moisture content or the force required to break the cookie.

There are various objective tests available for monitoring food quality. Fruits and vegetables may be graded for size by passing them through apertures of a specific size. Eggs also are graded in this manner, and consumers may choose among six sizes, including small, large, or jumbo-sized eggs. Flour is graded according to particle size, which is required to pass through sieves of specific mesh size.

Color may be measured objectively by several methods, ranging from simply matching the product to colored tiles to using the **Hunterlab color and color difference meter**. The color meter measures the intensity, chroma, and hue of the sample and generates three numbers for the sample under test. Thus, small changes in color can be detected. This method of color analysis is appropriate for all foods. For liquid products, such as apple juice, a **spectrophotometer** can be used to measure color. A sample is placed in the machine and a reading is obtained, which is proportional to the color and/or the clarity of the juice.

Food Rheology

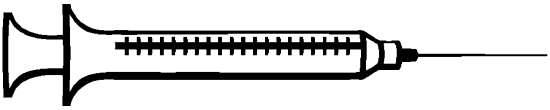
Many objective methods for measurement of food quality involve measurement of some aspect of texture, such as hardness, crispness, or consistency. As mentioned already, texture is related to the rheological properties of food, which determine how it responds when subjected to forces such as cutting, shearing, or pulling.

Rheological properties can be divided into three main categories. A food may exhibit *elastic* properties, *viscous* properties, or *plastic* properties, or a combination. In reality, rheological properties of most foods are extremely complex and they do not fit easily into one category.

Elasticity is a property of a solid and is illustrated by a rubber band or a coiled spring. If a force or *stress* is applied, the material will deform (stretch or be compressed) in proportion to the amount of force applied, and when the force is removed, it will immediately return to its original position. If sufficient force is applied to a solid, it will eventually break. The force required to break the material is known as the *fracture stress*.

Some solids are more elastic than others; examples of very elastic solids are springs and rubber bands. Bread dough also has elastic properties, although its rheology is complex and includes viscous and plastic components as well. All solid foods exhibit elastic properties to some degree.

Viscosity is a property of a liquid and is illustrated by a piston and cylinder (or a dashpot) or by a syringe. Viscosity is a measure of the resistance to flow of a liquid when subjected to a shearing force. The thicker the liquid, the greater its viscosity or resistance to flow. For example, water has a low viscosity and flows readily, whereas catsup is considered "thick", has a higher viscosity, and flows relatively slowly.



Liquids can be separated into ***Newtonian*** and ***non-Newtonian*** fluids. In the case of a Newtonian liquid, the shear stress applied to the fluid is proportional to the shear rate or shear velocity of the flowing liquid. This means that the viscosity is independent of the shear rate. Therefore, viscosity will be the same, even if the viscometer used to measure it is operated at different speeds. A graph of shear stress against shear rate would give a straight line, and the viscosity could be calculated from the gradient of the line (see Figure 1.4). The steeper the line, the greater the resistance to flow and the greater the viscosity of the liquid.

Examples of Newtonian liquids include water, sugar syrups, and wine. However, most liquid foods are non-Newtonian, in which case the consistency or apparent viscosity depends on the amount of shear stress applied. This can be seen

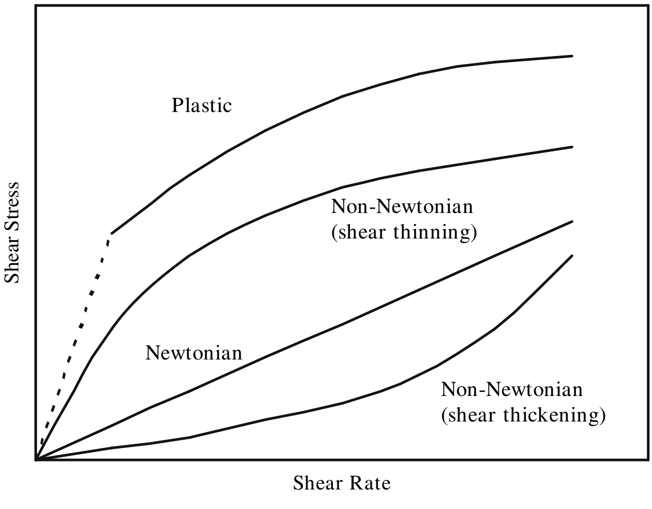


FIGURE 1.4 Schematic representation of flow behavior of Newtonian and non-Newtonian liquids [modified from Bowers, 1992 (6)].

with catsup, which appears fairly solid and is hard to get out of the bottle if it has been standing for a while. However, after shaking (applying a shear stress), the catsup becomes almost runny and will flow out of the bottle much more easily. If the bottle is again left to stand, the consistency of the undisturbed catsup will be regained after a short period of time. Shaking the bottle causes the molecules to align so that they flow over each other more easily and the apparent viscosity decreases. A graph of shear stress against shear rate would not give a straight line for catsup, since the apparent viscosity is not constant. (Strictly speaking, the term "apparent viscosity" should be used for non-Newtonian liquids, whereas the term "viscosity" should be reserved for Newtonian liquids.)

Some non-Newtonian liquids appear to get thicker when a shear stress is applied. In this case, the particles in the liquid tend to aggregate and trap pockets of liquid, thus making it harder for the molecules to flow over each other. Examples of such liquids include starch slurries and dilute solutions of some gums, such as alginates, carboxymethylcellulose, and guar gum.

The viscosity of both Newtonian and non-Newtonian liquids is affected by temperature. Higher temperatures cause liquids to flow more readily, thus decreasing viscosity, whereas lower temperatures cause an increase in viscosity. For this reason, it is important to make measurements of viscosity at a constant temperature and to specify that temperature.

A ***plastic*** substance can be molded, because it contains a liquid, but only after a certain minimum force (the *yield stress*) is applied. At forces below the yield stress it behaves as an elastic solid, but above the yield stress it behaves as a liquid. Examples of plastic substances include modeling clay, foods such as warm chocolate, and hydrogenated vegetable shortenings that can be creamed easily.

Some foods exhibit both elastic and viscous properties at the same time. They are termed *viscoelastic*. Bread dough is a good example of a viscoelastic material. When a force is applied, the material first deforms like an elastic solid, but then starts to flow. When the force is removed, it only partly regains its original shape.

The rheological properties of a food affect its texture and sensory properties. For example, brittleness, shortness, and hardness are related to the fracture stress of a solid food, whereas thickness and creaminess are related to the consistency or apparent viscosity of a liquid food. The rheological properties of many foods can be modified by adding stabilizers such as gums. These are added to increase viscosity, which in turn restricts movement of everything in the system and may delay undesirable changes, such as precipitation of solids or separation of emulsions.

Objective Measurement of Texture

Many objective methods for measurement of food quality involve measurement of some aspect of texture. For example, viscometers are used to measure viscosity or consistency of foods ranging from thin liquids such as oil to thick sauces such as catsup. The sophistication of these instruments also varies widely. The **Bostwick consistometer** is a simple device that involves filling a reservoir with the sample to be tested. A stopwatch is started, the gate holding the product in the reservoir is lifted, and the product is timed to flow a certain distance along the consistometer trough. At the other end of the scale, **Brookfield viscometers** are sophisticated instruments that may be used to measure viscosity under controlled temperature and when the sample is subjected to shearing forces of different magnitudes. The **Instron Universal Testing Machine** has various attachments that allow it to measure different aspects of texture, including compressibility of bread and the force required to break a cookie or to shear a piece of meat. The **Brabender amylograph** (Chapter 4) is an instrument that was developed to measure the viscosity of starch mixtures as they are heated in water. Another instrument with a very specific use is the mixograph, which is used to measure the ease of mixing of bread doughs. Sophisticated equipment, such as the **mass spectrophotometer, gas chromatography**, and **high-performance liquid chromatography** equipment are available in research and analytical laboratories for analysis of specific products or components.

The list of equipment used in the food industry for evaluating food quality would fill a complete textbook. Certain principles must be emphasized when considering objective tests to evaluate the quality of a food product:

- The objective test must be appropriate for the food product being tested. In other words, it must measure an attribute of the food that has a major effect on quality.
- Ideally, the objective test results should correlate with sensory testing of similar food products to make sure that the test is a reliable index of quality of the food.
- Most objective tests used to assess food quality are empirical; that is, they do not measure an absolute property of the food. However, the results are still meaningful, as long as instruments are calibrated with materials that have similar properties to the foods under test.
- Objective tests include all types of instrumental analysis, including laboratory tests to determine chemical composition, nutrient composition, and bacterial composition.
- Objective tests are repeatable and are not subject to human variation. If the equipment is properly maintained and is used correctly, it should give reliable results from day to day.

Objective tests are necessary to identify contaminants in foods and to reveal faulty processing methods as well as testing for deterioration such as rancidity in fats and oils. Objective tests are essential for routine quality control of foods and food products. However, they must correlate with sensory testing, because no single objective test can measure the overall acceptability of a specific food or food product.

An in-depth study of analysis of foods by objective methods is beyond the scope of this book. For more information, the reader is referred to *Food Analysis* by S. Suzanne Neilsen (10) and to the many other textbooks available on the subject.

COMPARISON OF SUBJECTIVE AND OBJECTIVE EVALUATION

Both *sensory evaluation* and *objective evaluation* of food quality are essential in the food industry in order to routinely monitor food quality and to ensure that the foods being produced are acceptable to consumers. The two methods of evaluation complement each other.

Sensory testing is expensive and time-consuming, because many panelists are required to test a single product in order for the results to be meaningful. On the other hand, objective testing is efficient and after the initial purchase of the necessary equipment relatively inexpensive. One person usually can perform an objective test on many samples in a day, whereas it may take a day to perform a complete sensory test on one or two samples. Objective tests give repeatable results, whereas sensory tests may give variable results due to variation of human responses and opinions.

While sensory evaluation gives a judgment of the overall acceptability of a product, an objective method of evaluation is only able to measure one aspect of the food, and this may not always be sufficient to determine whether the quality of the product is acceptable. The only true judge of acceptability of a food product is a consumer. Therefore, objective tests must correlate with sensory tests to give a reliable index of food quality.

Objective tests are essential for routine quality control of food products. However, sensory evaluation is essential for product research and development. Only consumers can tell whether there is a perceivable difference in a product when the formulation or packaging is changed and only consumers can determine whether a new product is acceptable or preferred over another brand.

SUBJECTIVE VERSUS OBJECTIVE ANALYSIS—OVERVIEW

Subjective/Sensory Analysis	*Objective Analysis*
Uses individuals	Uses equipment
Involves human sensory organs	Uses physical and chemical techniques
Results may vary	Results are repeatable
Determines human sensitivity to changes in ingredients, processing, or packaging	Need to find a technique appropriate for the food being tested
Determines consumer acceptance	Cannot determine consumer acceptance unless correlated with sensory testing
Time-consuming and expensive	Generally faster, cheaper, and more efficient than sensory testing
Essential for product development and for marketing of new products	Essential for routine quality control

CONCLUSION

Food quality can be defined as the degree of excellence of a food and includes factors such as taste, appearance, and nutritional quality, as well as its bacteriological or keeping quality. Food quality goes hand in hand with food acceptability and it is important that quality is monitored, both from a food safety standpoint and to ensure that the public likes a particular product and will continue to select it. Both sensory and objective methods are important in evaluation of food quality and the two methods complement one another. Sensory analysis is essential for development of new products, because only consumers can tell whether they like a product or not. However, objective testing also is important, especially for routine quality control of food products.

Engineers at food manufacturers are constantly developing new products both for “at-home” and eating out markets. The intent is to better serve the customer’s needs and wants.

GLOSSARY

Affective or acceptance/preference tests: Used to determine whether a specific consumer group likes or prefers a particular product.

Ballot: Sheet of paper on which the panelist receives pertinent sample information and instructions and on which observations are recorded during a sensory test.

Descriptive tests: Specialized difference tests used to describe specific flavor attributes of a product or to describe degree of difference between products.

Discrimination or difference tests: Used to determine if there is a perceivable difference between samples.

Duo–trio test: Samples include a reference food and two samples, one of which is the same as the reference.

Elasticity: Ability of a material to stretch when a force is applied and to return to its original position when the force is removed.

Likeability test: Panelists rate a sample on a hedonic scale from “dislike extremely” to “like extremely.”

Master sheet: Details the specific three-digit product numbers and positions for every panelist in a sensory test. Used to ensure that each product is seen an equal number of times in each position, so that bias is avoided.

Mouthfeel: Textural qualities of a food as perceived in the mouth.

Newtonian liquid: The viscosity is independent of the shear rate. Stirring or shaking does not make the liquid runnier or thicker. Examples are water, sugar syrups, and wine.

Non-Newtonian liquid: Apparent viscosity depends on the shear rate. Catsup gets thinner with increasing shear rate, whereas some gums thicken with increasing shear rate.

Objective evaluation: Involves use of physical and chemical techniques to evaluate food quality instead of variable human sensory organs.

Plasticity: Material flows when subjected to a certain minimum force; material can be molded.

***p*-Value**: Statistical probability that a result is significant. A *p* value of 0.01 indicates 99% confidence that a result is significant. In other words, out of 100 trials, the same result would be expected 99 times. The probability of the opposite result occurring is only 1 in 100 trials.

Ranking test: Panelists rank two or more samples in order of preference or intensity for a particular attribute.

Rheology: Science of the deformation and flow of matter, how a food reacts when force is applied; includes elasticity, viscosity, and plasticity.

Sensory testing: Use of senses to evaluate products; involves consumer opinion.

Threshold: Concentration required for identification of a particular substance.

Triangle test: Three samples, two of which are alike, one is odd.

Umami: Savory taste, given by substances such as monosodium glutamate.

Viscosity: Resistance to flow of a liquid when a shear force is applied. Liquids with a low viscosity flow readily, whereas liquids with a high viscosity flow slowly.

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CHAPTER 2

Water

INTRODUCTION

Water is abundant in all living things and consequently is in almost all foods, unless steps have been taken to remove it. It is essential for life, even though it contributes no calories to the diet. Water also greatly affects the texture of foods, as can be seen when comparing grapes and raisins (dried grapes), or fresh and wilted lettuce. It gives crisp texture or turgor to fruits and vegetables and also affects perception of the tenderness of meat. For some food products, such as potato chips, salt, or sugar, lack of water is an important aspect of their quality and keeping water *out* of such foods is important to maintain quality.

Almost all food processing techniques involve the use of water or modification of water in some form: freezing, drying, emulsification (trapping water in droplets), breadmaking, thickening of starch, and making pectin gels are a few examples. Further, because bacteria cannot grow without water, the water content has a significant effect on maintaining quality of the food. This explains why freezing, dehydration, or concentration of foods increases shelf life and inhibits bacterial growth.

Water is important as a solvent or dispersing medium, dissolving small molecules to form true solutions and dispersing larger molecules to form colloidal solutions. Acids and bases ionize in water; water also is necessary for many enzyme-catalyzed and chemical reactions to occur, including hydrolysis of compounds such as sugars. It also is important as a heating and cooling medium and as a cleansing agent.

Because water has so many functions that are important to a food scientist, it is important to be familiar with some of its unique properties. When modifying the water content of a food, it is necessary to understand these functions in order to predict the changes that are likely to occur during processing of such foods.

Drinking water is available to the consumer in convenient bottled and aseptic containers in addition to the tap.

CHEMISTRY OF WATER

The chemical formula for water is H_2O. Water contains strong ***covalent bonds*** that hold the two hydrogen atoms and one oxygen atom together. The oxygen can be regarded to be at the center of a tetrahedron, with a bond angle of 105° between the two hydrogen atoms in *liquid water* and a larger angle of 109°6′ between the hydrogens in *ice* (Figure 2.1).

The bonds between oxygen and each hydrogen atom are polar bonds, having a 40% partial ionic character. This means that the outer-shell electrons are unequally shared between the oxygen and hydrogen atoms, the oxygen atom attracting them more strongly than each hydrogen atom. As a result, each hydrogen atom is slightly positively charged and each oxygen atom is slightly negatively charged. Therefore they are able to form ***hydrogen bonds***.

A hydrogen bond is a *weak* bond between polar compounds where a hydrogen atom of one molecule is attracted to an electronegative atom of another molecule (Figure 2.2). It is a weak bond relative to other types of chemical bonds such as covalent or ionic bonds, but it is very important because it usually occurs in large numbers, and therefore has a significant cumulative effect on the properties of the substance in which it is found. Water can form up to four hydrogen bonds (oxygen can hydrogen-bond with two hydrogen atoms).

Water would be expected to be gas at room temperature if compared with similar compounds in terms of their positions in the periodic table, but because of the many hydrogen bonds it contains, it is liquid. Hydrogen bonds between hydrogen and oxygen are common, not just between water molecules but between many other types of molecules that are important in foods, such as sugars, starches, pectins, and proteins.

Due to its V-shape, each molecule of water can form up to four hydrogen bonds with its nearest neighbors. Each hydrogen atom can form one hydrogen bond, but the oxygen atom can form two, which results in a three-dimensional lattice in ice. The structure of ice is dynamic and hydrogen bonds are continually breaking and reforming between different water molecules. Liquid water also contains hydrogen bonds, and therefore has a variety of ordered structures that are continually changing as hydrogen bonds break and reform. In liquid water, it

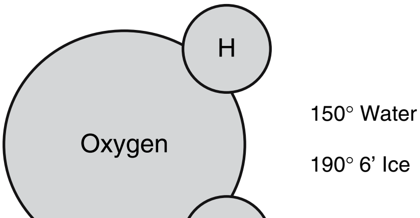

FIGURE 2.1 Bond angle of water and ice.

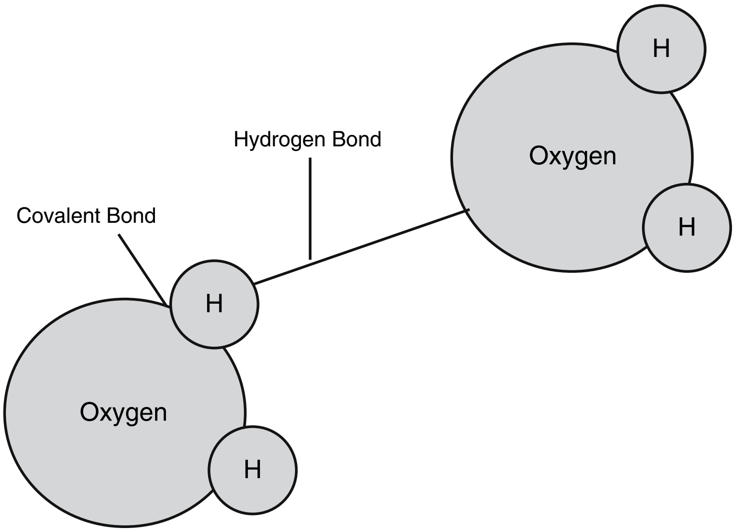

FIGURE 2.2 Hydrogen and covalent bonds in water molecules.

is estimated that about 80% of water molecules are involved in hydrogen bonding at any one time at 212°F (100°C), whereas 90% are involved in liquid water at 32°F (0°C).

Because *liquid* water has a smaller bond angle than ice, the molecules can be packed together more tightly, and so the *coordination number*, or in other words the average number of nearest neighbors is higher for water than for ice. The average distance between water molecules also is affected by temperature and increases with temperature as the molecules have more kinetic energy and can move around faster and farther at higher temperatures. Both of these affect the density of water, but the coordination number has a much more dramatic effect. Ice is less dense than water because the molecules have a smaller coordination number and cannot be packed together as tightly as water. Therefore, ice floats.

As water *freezes*, its density decreases and its *volume increases* by about 9%. This is very significant when freezing foods with high water content. Containers and equipment must be designed to accommodate the volume increase when the product freezes; for example, molds for popsicles must allow room for expansion. This volume increase also contributes to the damage to the structure of soft fruits on freezing. This is discussed in Chapter 7. As water is heated above 39°F (4°C), the increase in the average distance between molecules causes a slight decrease in density.

SPECIFIC HEAT AND LATENT HEAT OF WATER

When ice is heated, the temperature increases in proportion to the amount of heat applied. The ***specific heat*** of water is the energy (in calories or in joules) required to raise the temperature of 1 g of water by 1°C, and is the same whether heating water or ice. It is relatively high compared to other substances due to the hydrogen bonds. The specific heat of water is 1 cal/g per °C. This means that it takes 100 cal to raise the temperature of 1 g of water from 0 to 100°C.

Once ice has reached 0°C, energy needs to be put in to break the hydrogen bonds and enable ice to change to the liquid form. Until the ice has been converted to liquid, there is no further change in temperature until steam is created.

> The ***latent heat of fusion*** is the energy required to convert 1 g of *ice to water* at 0°C and is 80 cal; that is, 1 g of ice at the freezing point absorbs approximately 80 cal as it changes to the liquid state
>
> The ***latent heat of vaporization*** is the energy required to convert 1 g of *water into vapor* at 100°C and is 540 cal; that is, 1 g of water at the boiling point absorbs approximately 540 cal as it becomes steam.

Both the *specific heat* and *latent heat* for water are fairly high compared with most substances, and this is an important consideration when water is used as a medium of heat transfer. It takes considerable energy to heat water and that energy is then available to be transferred to the food. Foods *heated* in water are slow to heat. Water also must take up considerable heat to evaporate. It takes heat from its surroundings, thus, it is a good *cooling* agent.

When ice is subjected to vacuum and then heated, it is converted into vapor *without* going through the liquid phase. This phenomenon is known as ***sublimation*** and is the basis for the food processing method known as ***freeze-drying***. Coffee is an example of a food product that is freeze-dried. The process is expensive and is used only for foods that can be sold at a high price, such as coffee. The coffee beans are frozen and then subjected to a high vacuum, after which radiant heat is applied until almost all of water is removed by sublimation. Freezer burn also is the result of sublimation.

VAPOR PRESSURE AND BOILING POINT

Vapor Pressure

If a puddle of water is left on the ground for a day or two, it will dry up because the liquid evaporates. The water does not boil, but individual water molecules gain enough energy to escape from the liquid as vapor. Over a period, an *open*, small pool of water will dry up in this way. If the liquid is in a *closed* container, at equilibrium, some molecules are always evaporating and vapor molecules are condensing, so there is no overall change in the system. The *vapor* (gaseous) molecules that have escaped from the *liquid* state exert a pressure on the surface of the liquid known as the ***vapor pressure***.

When the vapor pressure is *high*, the liquid evaporates (is vaporized) easily and *many* molecules exist in the vapor state; the boiling point is low. Conversely, a *low* vapor pressure indicates that the liquid does not vaporize easily and that there are few molecules existing in the vapor state. The boiling point for these liquids is higher. The liquid boils when the vapor pressure reaches the external pressure.

The vapor pressure increases with increasing temperature. At higher temperatures, the molecules have more energy and it is easier for them to overcome the forces holding them within the liquid and to vaporize; so there are more molecules in the vapor state.

The vapor pressure decreases with addition of solutes, such as salt or sugars. In effect, the solutes dilute the water; therefore, there are fewer water molecules (in the same volume) available for vaporization, and thus, there will be fewer molecules in the vapor state and the vapor pressure will be lower. Attraction to the solute also limits evaporation.

Boiling Point

Anything that lowers the vapor pressure (pressure by gas above the liquid) increases the boiling point. This is due to the fact that as the vapor pressure is lowered at a particular temperature, more energy must be put in; in other words, the temperature must be raised to increase the vapor pressure again. The external pressure does not change if salts or sugars are added, but it is more difficult for the molecules to vaporize; so the temperature at which the vapor pressure is the same as the external pressure (boiling point) will be higher. One mole of sucrose elevates the boiling point by 0.52°C and 1 mole of salt elevates the boiling point by 1.04° C. Salt has double the effect of sucrose because it is ionized, and for every mole of salt, there is 1 mole of sodium ions and 1 mole of chloride ions. Salts and sugars depress the freezing point of water in a similar fashion.

If the external pressure is increased by heating in a pressure cooker or retort (commercial pressure cooker), the boiling point increases and a shorter time than normal is required to cook a particular food (the basis of preserving foods by canning). For example, food may be heated in cans in retorts, and the steam pressure is increased to give a boiling point in the range 239–250°F(115–121°C). Conversely, if the external pressure is decreased, for example, at high altitude, water boils at a lower temperature and so food may require a longer time to cook.

CULINARY ALERT! Even when water comes to a rapid boil in high altitude locations, the temperature it is not as hot as rapidly boiling water at sea level.

WATER AS A DISPERSING MEDIUM

Substances are either *dissolved, dispersed, or suspended* in water depending on their particle size and solubility. Each is described below. Water is the usual dispersion medium.

Solution

Water *dissolves* small molecules such as salts, sugars, or water-soluble vitamins to form a true ***solution***, which may be either **ionic** or **molecular** (a discussion of unsaturated, saturated, and supersaturated solutions appears in Chapter 14).

An ionic solution is formed by dissolving substances that ionize in water, such as salts, acids, or bases. Taking sodium chloride as an example, the solid contains sodium (Na^+) and chloride (Cl^-) ions held together by ionic bonds. When placed in water, the water molecules reduce the attractive forces between the oppositely charged ions, the ionic bonds are broken, and the individual ions become surrounded by water molecules, or **hydrated**. Each ion is usually surrounded by six water molecules; the ions move independently of each other.

Polar molecules, such as sugars, which are associated by hydrogen bonding, dissolve to form **molecular solutions**. When a sugar crystal is dissolved, hydrogen-bond interchange takes place and the hydrogen bonds between the polar hydroxyl groups on the sugar molecules are broken and replaced by hydrogen bonds between water and the sugar molecules. Thus, the sugar crystal is gradually hydrated; each sugar molecule being surrounded by water molecules.

Water molecules bind to polar groups on the sugar molecules by hydrogen bonds. The sugar molecules are removed from the sugar crystal and hydrated as water molecules surround them and bind to them by hydrogen bonds.

When a hydrogen-bond interchange is involved, solubility increases with increasing temperature. Heating disrupts hydrogen bonds and reduces water–water and sucrose–sucrose attraction, thus facilitating formation of hydrogen bonds between water and sucrose and hydration of sucrose molecules. Therefore, sucrose is much more soluble in hot water than in cold water. Solutes increase the boiling point of water, and the dramatic increase in sucrose solubility with temperature, particularly at temperatures above 100°C (the boiling point of pure water), makes it possible to determine the sucrose concentration by measuring the boiling point of sucrose solution (Chapter 13). This is important when making candies or pectin jellies.

Colloidal Dispersion

Molecules that are *too big* to form true solutions may be dispersed in water. Those with a particle size range *1–100 nm* are dispersed to form a ***colloidal dispersion*** or ***sol***. Examples of such molecules include cellulose, *cooked* starch, pectic substances, gums, and some food proteins. Colloidal dispersions are often unstable; thus, food scientists must take care to stabilize them where necessary if they occur in food products. They are particularly unstable to factors such as heating, freezing, or pH change. Changing the conditions in a stable dispersion can cause precipitation or gelation; this is desirable in some cases, for example, when making pectin jellies.

(The reader is referred to Chapter 4 for a discussion of sols and gels, but *sol* is a colloid that pours—a two-phase system with a solid dispersed phase in a liquid continuous phase, for example, a hot sauce. A ***gel*** also is a two-phase system, containing an elastic solid with a liquid dispersed phase in a solid continuous phase.)

Colloid science is important to food scientists as many convenient or packaged foods have colloidal dimensions and their stability and sensitivity to certain types of reactions can be understood only with knowledge of colloid science.

Suspension

Particles that are *larger than 100* nm are too large to form a colloidal dispersion. These form a ***suspension*** when mixed with water. The particles in a suspension separate out over a period, whereas no such separation is observed with colloidal dispersions. An example of a suspension would be *uncooked* starch grains in water. It may be temporarily suspended and then easily settle out, no longer "suspended," but rather falling to the bottom of the container/pan.

CULINARY ALERT! Starches remain suspended throughout the liquid by stirring. They do not "dissolve." If left undisturbed, they settle downward, and a sediment is observed at the bottom of the container.

FREE, BOUND, AND ENTRAPPED WATER

Water is abundant in all living things, and consequently in almost all foods, unless steps have been taken to remove it. Most natural foods contain water up to 70% of their weight or greater unless they are dehydrated, and fruits and vegetables contain water up to 95% or greater. Water that can be extracted easily from foods by squeezing or cutting or pressing is known as ***free water***, whereas water that cannot be extracted easily is termed as ***bound water***.

Bound water usually is defined in terms of the ways it is measured; different methods of measurement give different values for bound water in a particular food. Many food constituents can bind or hold onto water molecules, such that they cannot be removed easily and they do not behave like liquid water. Some characteristics of bound water include:

- It is not free to act as a solvent for salts and sugars.
- It can be frozen only at very low temperatures (below freezing point of water).
- It exhibits essentially no vapor pressure.
- Its density is greater than that of free water.

Bound water has more structural bonding than liquid or free water; thus, it is unable to act as a solvent. As the vapor pressure is negligible, the molecules cannot escape as vapor; the molecules in bound water are more closely packed than in the liquid state, so the density is greater. An example of bound water is the water present in cacti or pine tree needles—the water cannot be squeezed or pressed out; extreme desert heat or a winter freeze does not negatively affect bound water and the vegetation remains alive. Even upon dehydration, food contains bound water.

Water molecules bind to polar groups or ionic sites on molecules such as starches, pectins, and proteins. Water closest to these molecules is held most firmly; the subsequent water layers are held less firmly and are less ordered, until finally the structure of free water prevails. A more detailed discussion of bound water is given in food chemistry books, for example, Fennema (1).

Water also may be **entrapped** in foods such as pectin gels, fruits, vegetables, and so on. Entrapped water is immobilized in capillaries or cells, but if released during cutting or damage, it flows freely. Entrapped water has properties of free water and no properties of bound water.

CULINARY ALERT! Freshness of any produce is evaluated in part by the presence of water. Food items appear more wilted when free water is increasingly lost through dehydration.

WATER ACTIVITY (A_w)

Water activity, or A_w, is a ratio of the vapor pressure of water in a solution (P_s) to the vapor pressure of pure water (P_w):

$$\boxed{A_w = P_s/P_w}$$

A_w must be high as living tissues require sufficient level of water to maintain turgor. However, microorganisms such as bacteria, mold, and yeast multiply at a high A_w. Because their growth must be controlled, preservation techniques against spoilage due to these microorganisms take into account the water activity of the food. Less bacterial growth occurs if the water level is lowered to less than 0.85 (FDA Model Food Code). Of course, there are other factors in addition to the water that must be present for bacterial growth to occur (food, optimum pH, etc.).

Jams, jellies, and preserves are prepared using high concentrations of sugar and brines, which contain high concentrations of salt, which are used to preserve hams. Sugar and salt are both effective preservatives as they lower A_w. Salt lowers A_w even more effectively than sugar due to its chemical structure, which ionizes and attracts water.

ROLE OF WATER IN FOOD PRESERVATION AND SHELF LIFE OF FOOD

Drying and *freezing* are common food preservation techniques. Foods are dehydrated or frozen to reduce the available water and extend shelf life.

The control of water level in foods is an important aspect of food quality as water content affects the shelf life of food. For example, foods may be more desirable either crispy or dry. Freezing and drying are common food preservation processes that are used to extend the shelf life of foods because they render water unavailable for pathogenic or spoilage bacteria. If the water in foods is frozen quickly, there is less damage to the food at the cellular level. Preservatives

(Chapter 16) may be added to a formulation to prevent mold or yeast growth. Humectants, which have an affinity for water, are added to retain moisture in foods.

WATER HARDNESS AND TREATMENTS

The hardness of water is measured in parts per million or in "grains," with one grain equivalent to 0.064 g of calcium carbonate. ***Soft water*** contains 1–4 grains per gallon of some organic matter and has no mineral salts. ***Hard water*** contains 11–20 grains per gallon. Water may exhibit *temporary* hardness due to iron or calcium and magnesium bicarbonate ions [$Ca(HCO)_3)_2$ and $Mg(HCO_3)_2$]. The water may be softened by boiling (soluble bicarbonates precipitate when boiled and leave deposits or scales) and insoluble carbonates may be removed from the water.

Permanently hard water *cannot* be softened by boiling as it contains either calcium or magnesium sulfates ($CaSO_4$ or $MgSO_4$) as well as other salts that are not precipitated by boiling. Permanent hard water may be softened only by the use of chemical softeners. Hard water exhibits less cleaning effectiveness than soft water due to the formation of insoluble calcium and magnesium salts with soap, which could be prevented by the use of detergents.

Water has a pH of 7, or neutral; tap water displays a variance on either side of neutral. It may be slightly alkaline or slightly acidic depending on the source and so forth. Hard water has a pH of up to 8.5. Chlorinated water is that which has had chlorine added to kill or inhibit the growth of microorganisms. Manufacturing or processing plants may require chemically pure water to prevent turbidity, off-color, and off-flavor. Tap water may not be sufficiently pure for use in food products.

BEVERAGE CONSUMPTION

"Drinking water was ranked as the preferred beverage to fulfill daily water needs and was followed in decreasing value by tea and coffee, low-fat (1.5% or 1%) and skim (nonfat) milk and soy beverages, noncalorically sweetened beverages, beverages with some nutritional benefits (fruit and vegetable juices, whole milk, alcohol, and sports drinks), and calorically sweetened, nutrient-poor beverages" (2).

CONCLUSION

Water is essential for life and makes up the major part of living tissue. The nature of hydrogen bonds allows water to bond with other water molecules as well as with sugar, starches, pectins, and proteins. Water absorbs energy as it changes from frozen to liquid to vapor state and is an effective cooling medium. If water is easily extracted from foods by squeezing or pressing, it is known as free water.

Inversely, water that is not easily removed from foods and that is not free to act as a solvent is known as bound water; water in foods imparts freshness. A measure of water activity is the ratio of the vapor pressure of water in a solution to the vapor pressure of pure water. If water is unavailable for pathogenic or spoilage-causing bacteria to multiply, food is better preserved and has a longer shelf life.

GLOSSARY

Bound water: Water that cannot be extracted easily; it is bound to polar and ionic groups in the food.

Colloidal dispersion: Molecules, larger than those in solution, dispersed in the surrounding medium.

Covalent bonds: Strong bonds that hold the two hydrogen atoms and one oxygen atom together in a water molecule.

Free water: Water that can be extracted easily from foods by squeezing, cutting, or pressing.

Freeze-drying: A food-processing method that converts ice to vapor without going through the liquid phase (sublimation).

Gel: Elastic solid; a two-phase system that contains a solid continuous phase and a liquid dispersed phase.

Hard water: Contains 11–20 grains per gallon. Hardness is due to calcium and magnesium bicarbonates or sulfates, which results in less effective cleaning.

Hydrogen bonds: Weak bonds between polar compounds where a hydrogen atom of one molecule is attracted to an electronegative atom of another molecule.

Latent heat of fusion: The energy required to convert 1 g of ice to water at 0°C—requires 80 cal.

Latent heat of vaporization: The energy required to convert 1 g of water to vapor at 100°C—requires 540 cal.

Sol: A two-phase system with a solid dispersed in a liquid continuous phase; pourable.

Soft water: Contains one to four grains per gallon, no mineral salts, some organic matter.

Solution: (ionic or molecular) small molecules dissolved in water.

Sublimation: When ice is subjected to vacuum and then heated, it gets converted to vapor without going through the liquid phase; basis for freeze-drying; occurs in freezer burn.

Specific heat: The energy required to raise the temperature of 1 g of water by 1°C whether heating water or ice; requires 1 cal/g per °C.

Suspension: Molecules larger than those in a solution or dispersion that are mixed with the surrounding medium. A *temporary* suspension settles upon standing.

Vapor pressure: The pressure vapor molecules exert on the liquid.

Water activity ($A_{\mathbf{w}}$): The ratio of the vapor pressure of water in a solution to the vapor pressure of pure water.

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PART II

Carbohydrates

CHAPTER 3

Carbohydrates in Food: An Introduction[1]

INTRODUCTION

Carbohydrates are organic compounds containing carbon, hydrogen, and oxygen, and they may be simple or complex molecules. Historically, the term "carbohydrate" has been used to classify all compounds with the general formula $C_n(H_2O)_n$ as the hydrates of carbon. Important food carbohydrates include simple sugars, dextrins, starches, celluloses, hemicelluloses, pectins, and gums. They are an important source of energy or fiber in the diet, and they also are important constituents of foods because of their functional properties. Carbohydrates may be used as sweeteners, thickeners, stabilizers, gelling agents, and fat replacers. The simplest carbohydrates are known as monosaccharides or sugars, and they have the general formula $C_nH_{2n}O_n$. The most common ones contain six carbon atoms. Disaccharides contain two sugar units, trisaccharides contain three, oligosaccharides contain several units, and polysaccharides are complex polymers containing as many as several thousand units linked together to form a molecule.

MONOSACCHARIDES

Monosaccharides are simple carbohydrates containing between three and eight carbon atoms, but only those with five or six carbon atoms are common. Two of the most important ones in foods are the six-carbon sugars glucose and fructose. These have the general formula $C_6H_{12}O_6$.

Examples of Monosaccharides

Glucose. Glucose is known as an ***aldose sugar*** because it contains an aldehyde group (CHO) located on the first carbon atom of the chain. It is conventional

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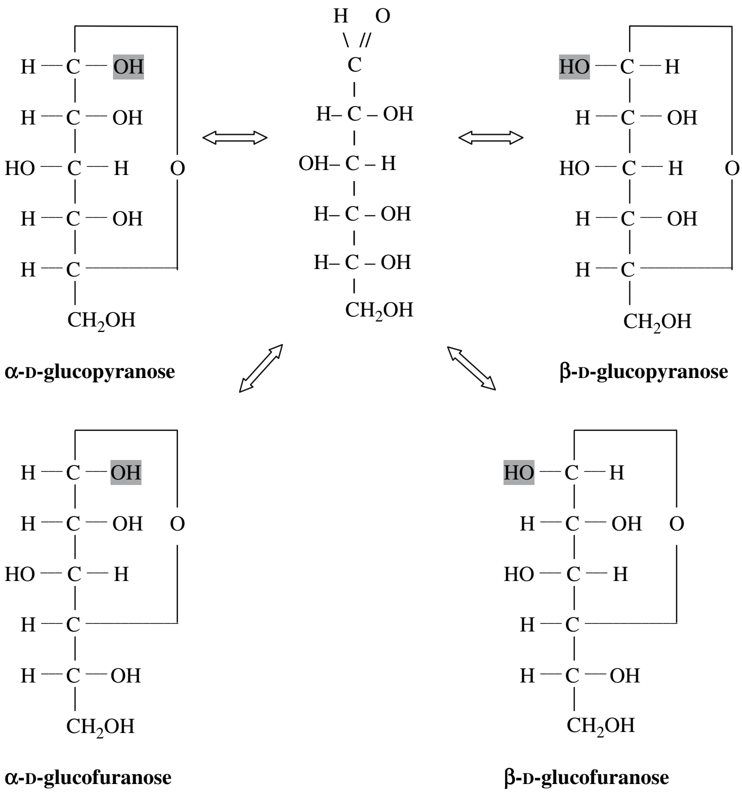
[1] For use with subsequent carbohydrate food chapters.

to number the carbon atoms along the chain so that the carbon atom with the highest number is farthest away from the aldehyde (or functional) group. The aldehyde group therefore is located on carbon one in glucose (and in all other aldose sugars). The numbering of the carbon atoms in glucose is shown above.

Two isomers of glucose exist, which are mirror images of each other: D-glucose and L-glucose. D-Glucose is the isomer that occurs naturally.

In fact, there are two series of aldose sugars, known as the D-series and the L-series, each formed by adding CHOH groups to build the carbon chain, starting from the smallest aldose sugar, which is D- or L-glyceraldehyde.

Each H–C–OH group within the chain is asymmetrical (since the H and OH groups are different). The highest-numbered asymmetric carbon atom of each D-series sugar has the same configuration as D-glyceraldehyde, rather than its L-isomer. In glucose, the highest-numbered asymmetric carbon atom is carbon-5. This is termed the ***reference carbon atom***, because its configuration determines whether the sugar belongs to the D series or to the L series. The hydroxyl group attached to it is called the ***reference hydroxyl group***. This group is always on the right side in a D-series sugar.

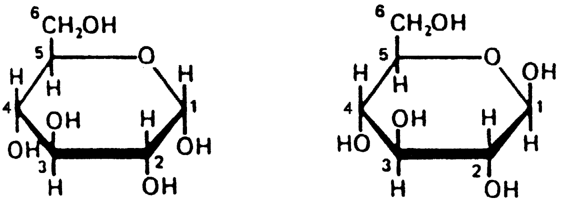

α-D-glucopyranose

β-D-glucopyranose

α-D-glucofuranose

β-D-glucofuranose

FIGURE 3.1 The main isomers of D-glucose (Fischer projections).



α-D-glucopyranose β-D-glucopyranose

FIGURE 3.2 The D-glucopyranose anomers, drawn according to the Haworth convention.

The straight-chain configuration of glucose (and of other monosaccharides) does not account for all the properties of the molecule. In reality, the straight-chain form exists in equilibrium with several possible ring configurations. In other words, the different configurations exist together in solution in a delicate balance. Glucose can exist in four ring structures: two pyranose or six-membered ring forms and two furanose or five-membered ring forms. These exist along with the straight-chain form, as shown in Figure 3.1.

The most common configurations for glucose are the ***pyranose*** structures, drawn according to the Haworth convention in Figure 3.2. These are ***anomers*** and are designated ***alpha*** (α) and ***beta*** (β). They are formed when the hydroxyl group on the fifth carbon reacts with the carbonyl group (located on Cl). As the ring closes, a new hydroxyl group is formed on Cl. This is termed the ***anomeric hydroxyl group***, and the carbon atom to which it is attached is termed the ***anomeric carbon atom***. For glucose and the other aldoses, the anomeric carbon atom always is the first carbon atom of the chain.

The anomeric hydroxyl group can project toward either side of the ring, as shown in Figure 3.2. Hence, there are two possible pyranose structures.

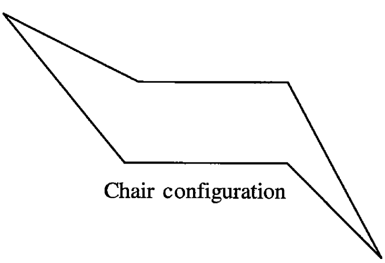
For glucose and all the hexoses, the α-anomer has the anomeric hydroxyl group on the *opposite* face of the ring to carbon-6 (ie, pointing in the opposite direction to carbon-6) when drawn according to the Haworth convention, whereas the β-anomer has the anomeric hydroxyl group on the *same* face of the ring as carbon-6 (ie, pointing in the same direction as carbon-6). For the D-series sugars, when the ring closes, carbon-6 always is located above the plane of the ring. Therefore, in the case of the α-anomer, the anomeric hydroxyl group points *down* or *below* the plane of the ring, whereas in the case of the β-anomer the anomeric hydroxyl group points *up* or *above* the plane of the ring.

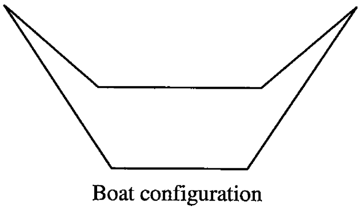
alpha anomer—anomeric hydroxyl group is on the **opposite** face of the ring to carbon-6 D-**series sugars**—anomeric hydroxyl group points **down**

beta anomer—anomeric hydroxyl group is on the **same** face of the ring as carbon-6 D-**series sugars**—anomeric hydroxyl group points **up**

[For the chemists who prefer to define the alpha- and beta-configurations according to the reference carbon, when the anomeric hydroxyl group is formed on the same side of the ring as the reference hydroxyl group (as seen in the Fischer projection formula), the anomer is denoted alpha, whereas when it is formed on the opposite side, it is denoted beta.]

In solution, the alpha- and beta-forms are in equilibrium, but the configuration can be fixed if the molecule reacts to form a disaccharide. It is important to know whether the configuration is fixed as the alpha- or beta-configuration, because this affects properties of the molecule, including digestibility. For example, starch contains α-D-glucose molecules and so can be digested, but cellulose contains β-D-glucose molecules and is indigestible. Although the ring structures are drawn with flat faces in the Haworth formulae, in reality they are not planar rings but are bent, and could be visualized more as a boat or a chair configuration.





The different configurations of glucose and the relationships between them are complex and are beyond the scope of this book. For a more in-depth treatment, interested readers are referred to books such as food chemistry, edited by Owen Fennema, or to basic biochemistry textbooks.

Glucose is the most important aldose sugar. Two other aldose sugars important in foods include galactose and mannose. Galactose is important as a constituent of milk sugar (lactose), and mannose is used to make the sugar alcohol mannitol, which is used as an alternative sweetener in chewing gum and other food products. These are both D-series sugars. In fact, almost all naturally occurring monosaccharides belong to the D-series.

Fructose. Fructose is a six-carbon sugar, like glucose, but it is a **ketose sugar**, not an aldose, because it contains a ketone group and not an aldehyde group. Like the aldose sugars, there is a D-series and an L-series of ketose sugars, but D-fructose is the only ketose of importance in foods. All ***ketose sugars*** contain a ketone group, not an aldehyde group.

In fructose, the ketone group is located on the second carbon of the chain. The second carbon atom therefore is the anomeric carbon in fructose. Fructose occurs mainly in the α- and β-***furanose***, or five-membered ring configurations, as shown in Figure 3.3.

Both the ketone groups of a ketose sugar and the aldehyde group of an aldose sugar may be called a ***carbonyl group***. A carbonyl group contains a carbon atom

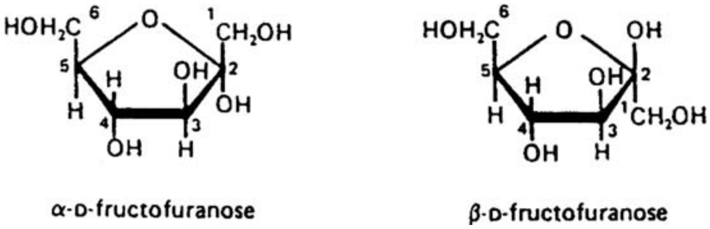


FIGURE 3.3 The main configurations of D-fructose.

double-bonded to an oxygen atom, but the other atoms are not specified. Hence, an aldehyde group is a specific type of carbonyl group, with both a hydrogen atom and an oxygen atom attached to the carbon atom. A ketone group also is a carbonyl group, because it contains an oxygen atom double-bonded to a carbon atom located within a hydrocarbon chain.

DISACCHARIDES

Disaccharides contain two monosaccharides joined together with a special linkage, called a **glycosidic** bond. Several disaccharides are important in foods—sucrose or table sugar is the most common and contains glucose and fructose. There are other important disaccharides, such as maltose containing two glucose units and lactose with glucose and galactose. Lactose also is known as milk sugar because it is found in milk. It is the least sweet and least soluble of the sugars.

Glycosidic Bonds

A ***glycosidic bond*** is formed when the carbonyl group of one monosaccharide reacts with a hydroxyl group of another molecule and water is eliminated (see Figure 3.4). Formation of a glycosidic link fixes the configuration of the monosaccharide containing the involved carbonyl group in either the α- or β-position. Therefore, it is necessary to specify whether the link is an α- or a β-link. The position of the bond also must be specified. For example, when two glucose molecules are joined to make maltose, the glycosidic link occurs between carbon-1 of the first glucose molecule and carbon-4 of the second, and the configuration

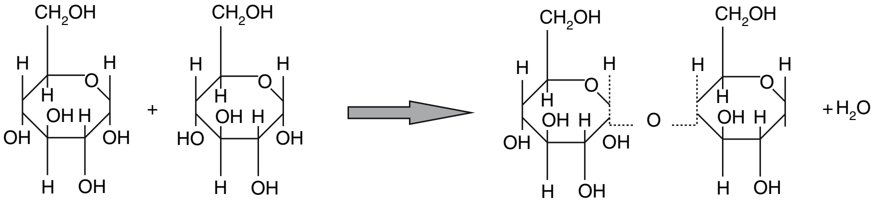


FIGURE 3.4 A glycosidic bond between the carbonyl and hydroxyl groups of monosaccharides.

of the first glucose molecule is fixed in the α-position. Maltose therefore contains two glucose units linked by an α-1,4-glycosidic bond. The anomeric hydroxyl group that is not involved in the glycosidic bond (ie, the one on the second glucose molecule) remains free to assume either the α- or β-configuration. Therefore, there are two forms of the disaccharide in equilibrium with each other. Glycosidic bonds are stable under normal conditions, but can be hydrolyzed by acid and heat or by enzymes such as sucrase, invertase, or amylases.

GLYCOSIDIC BOND

- Formed between the free carbonyl group of one monosaccharide and a hydroxyl group of another monosaccharide
- Fixes the configuration of the monosaccharide containing the involved carbonyl group in either the α- or β-position
- It is necessary to specify
  - The **configuration** of the link—whether it is an α-link or a β-link
  - The **position** of the link—it is numbered according to the respective positions of the two carbon atoms it links together. For example, an α-1,4 link glycosidic link would occur between carbon-1 of the first monosaccharide and carbon-4 of the second monosaccharide, as in maltose
- Readily hydrolyzed by
  - Heat and acid
  - Certain enzymes, such as sucrase, invertase, amylases, and so forth

Examples of Disaccharides

Maltose and Cellobiose. As has been mentioned already, maltose contains two glucose units linked by an α-1, 4-glycosidic bond. When two glucose molecules are joined together and the configuration of the first glucose molecule is fixed in the β-position, cellobiose is formed. Cellobiose contains a β-1,4-glycosidic bond. The chemical formulas for maltose and cellobiose are shown in Figure 3.5.

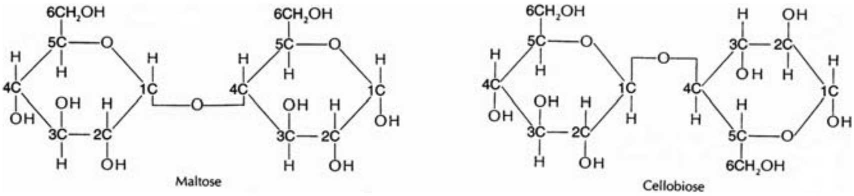


FIGURE 3.5 Maltose and cellobiose.

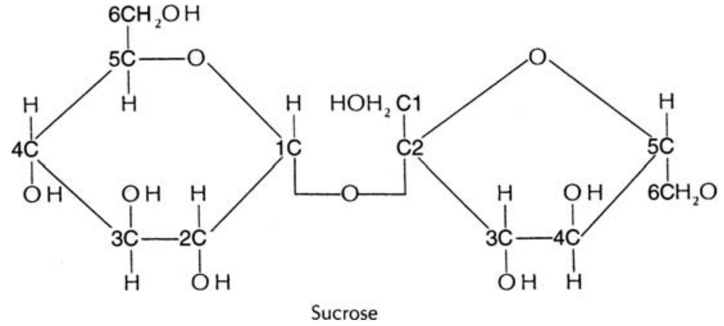


FIGURE 3.6 Sucrose.

Maltose is the building block for *starch*, which contains α-1,4-glycosidic bonds. Alpha links can be broken down by the body, so starch is readily digested. Cellobiose is the building block for *cellulose*, which contains β-1,4-glycosidic bonds. Cellulose cannot be digested in the human body because the β-linkages cannot be broken down by the digestive enzymes. Therefore, cellulose is known as dietary fiber. (The glycosidic bonds in cellulose cross the plane of the monosaccharide units they join together, and so they may be termed cross-planar bonds. It is because they are cross-planar that they are not digestible. In reality, because of the orientation of the bonds, the monosaccharide units tend to twist or flip over, as drawn in Figure 3.5, which results in a twisted ribbon effect for the polymer chain.)

Sucrose. Sucrose is the most common disaccharide and it contains glucose and fructose joined together by an α-1,2-glycosidic link (see Figure 3.6). The carbonyl groups of both the glucose and the fructose molecule are involved in the glycosidic bond; thus, the configuration of each monosaccharide becomes fixed. Glucose is fixed in the α-configuration, whereas fructose is fixed in the β-configuration. Sucrose can be hydrolyzed to glucose and fructose by heat and acid or by the enzymes invertase or sucrase. The equimolar mixture of glucose and fructose produced in this way is called ***invert sugar***. Production of invert sugar is important during the formation of candies and jellies, as invert sugar prevents unwanted or excessive crystallization of sucrose. (For further discussion of crystallization of sucrose, see Chapter 14.)

SOME PROPERTIES OF SUGARS

Sweetness

The most obvious sensory property of sugars such as glucose, fructose, and sucrose is their **sweetness**, which varies depending on the specific sugar. Lactose (milk sugar) is the least sweet, whereas fructose is the sweetest sugar. Sugars are used as sweeteners in candies and many other food products.

Formation of Solutions and Syrups

Sugars are soluble in water and readily form syrups. If water is evaporated, crystals are formed. Sugars form **molecular solutions** due to hydrogen-bond interchange. When sugar is placed in water, the water molecules form hydrogen bonds with the sugar molecules, thus hydrating them and removing them from the sugar crystals. Solubility increases with temperature; thus, a hot sucrose solution may contain more solute than a cold one. (For a discussion of molecular solutions, see Chapter 2.)

If a hot, saturated sucrose solution is cooled without disturbance, it will supercool and a supersaturated solution will be obtained. A ***supersaturated solution*** contains more solute than could normally be dissolved at that temperature. It is unstable and if stirred or disturbed, the extra solute will rapidly crystallize out of solution. Supersaturated solutions are necessary in candymaking. For more detail on sugar crystallization and candies, see Chapter 14.

Body and Mouthfeel

Sugars contribute body and "mouthfeel" to foods. In other words, the addition of sugar makes a food more viscous or gives it a less runny consistency. If sugar is replaced by a nonnutritive or high-intensity sweetener such as aspartame or saccharin, the consistency of the food will be watery and thin. To prevent this, another substance has to be added to give the expected body or mouthfeel to the food. Modified starches or gums usually are added to such food products to give the desired consistency without addition of sugar.

Fermentation

Sugars are readily digested and metabolized by the human body and supply energy (4 cal/g). They also are metabolized by microorganisms. This property is important in breadmaking, where sugar is fermented by yeast cells. The yeast feeds on the sugar, producing carbon dioxide, which is the leavening agent and causes bread dough to rise before and during baking.

Preservatives

At high concentrations, sugars prevent growth of microorganisms because they reduce the water activity of food to a level below which bacterial growth cannot be supported. Sugars therefore can be used as preservatives. Examples of foods preserved in this manner include jams and jellies.

Reducing Sugars

Sugars that contain a free carbonyl group are known as ***reducing sugars***. All monosaccharides are reducing sugars. Disaccharides are reducing sugars only if they contain a free carbonyl group. Sucrose is not a reducing sugar because it does not contain a free carbonyl group. The carbonyl groups of glucose and fructose are both involved in the glycosidic bond, and therefore are not free to take part in other reactions. Maltose, on the other hand, has one carbonyl group involved in the glycosidic bond and the other carbonyl group is free; thus, maltose is a reducing sugar.

Reducing sugars give brown colors to baked goods when they combine with free amino acid groups of proteins in a browning reaction called the ***Maillard reaction*** (this reaction is discussed further in Chapter 8).

Caramelization

Sugars ***caramelize*** on heating, giving a brown color. Caramelization is caused by the decomposition of the sugars and occurs at extremely high temperatures. A variety of compounds are formed as a result, including organic acids, aldehydes, and ketones. The reaction does not involve proteins and should not be confused with the Maillard browning reaction.

Sugar Alcohols

Reduction of the carbonyl group to a hydroxyl group gives ***sugar alcohols*** such as xylitol, sorbitol, and mannitol. These compounds are sweet, although not as sweet as sucrose. However, they are not fermented as readily as sugar by microorganisms in the mouth and so they are noncariogenic. (In other words, they do not cause tooth decay.) Therefore, they are used in chewing gum, breath mints, and other products that may be kept in the mouth for a while. Although products containing sugar alcohols may be labeled as "sugar free," it is important to realize that sugar alcohols are not free of calories. They are not metabolized as efficiently as sugars and have a lower caloric value (between 1 and 3 kcal/g). Sugar alcohols may be used as a low-energy bulk ingredient (in place of sugar) in many food products. Because sorbitol is mostly transformed to fructose in the body rather than glucose, it is tolerated by diabetics. Hence, it can be used to replace sugar in diabetic foods. The use of sugar alcohols is discussed further in Chapters 14 and 18.

OLIGOSACCHARIDES

Oligosaccharides contain a few (3–10) monosaccharide residues linked together by glycosidic bonds. Common ones include raffinose and stachyose. Raffinose is a ***trisaccharide*** and contains galactose, glucose, and fructose. Stachyose contains glucose, fructose, and two galactose units. Both occur in legumes such as dry beans and peas. They are not hydrolyzed or digested by the human digestive system and become food for bacteria in the large intestine. The bacteria metabolize the carbohydrates and produce gas, causing varying degrees of discomfort.

POLYSACCHARIDES

The most important food ***polysaccharides*** are the starches, pectins, and gums. All are complex carbohydrate polymers with different properties, which depend on the sugar units that make up the molecule, the type of glycosidic linkages, and the degree of branching of the molecules. Starches are discussed in Chapter 4 and pectins and other polysaccharides are covered in Chapter 5.

Dextrins and Dextrans

Dextrins are intermediate-chain-length glucose polymers formed when starch is broken down or hydrolyzed. They are larger than oligosaccharides but considerably shorter than starch molecules. Dextrins contain glucose molecules joined by α-1,4-glycosidic bonds and they are linear polymers. They are found in corn syrups produced by hydrolysis of starch.

Dextrans also are intermediate-chain-length glucose polymers, but they contain α-1,6-glycosidic bonds. They are produced by some bacteria and yeasts.

Starch

Starch is a glucose polymer that contains two types of molecules known as amylose and amylopectin. These are shown in Figures 3.7 and 3.8, respectively. Both are long chains of glucose molecules joined by α-1,4-glycosidic bonds; however, amylose is a linear chain, whereas amylopectin contains branches. For every 15–30 glucose residues there is a branch, joined to the main chain by an α-1, 6-glycosidic link. The branches make amylopectin less soluble in water than amylose. Usually, the two types of starch occur together, but starches may contain only amylose or only amylopectin. They have different properties, which are discussed in Chapter 4.

Starches also can be modified to give specific functional properties in food products, so knowledge of the properties of different starches is important in the food industry. Chapter 4 gives detailed information on characteristics of different starches and their uses in foods.

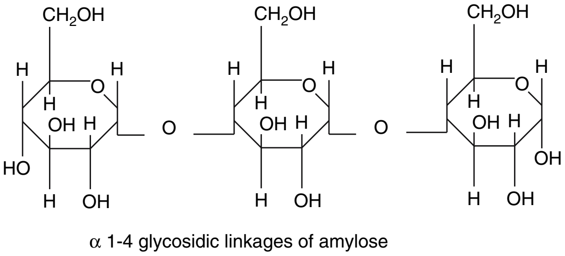
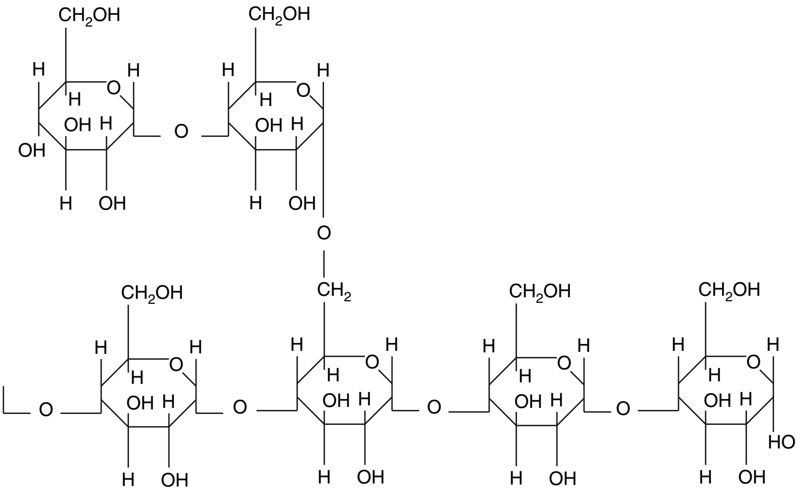


FIGURE 3.7 Amylose.



α 1-6 branching of amylopectin

Figure 3.8 Amylopectin.

Pectins and Other Polysaccharides

Pectins, gums, and seaweed polysaccharides also are important carbohydrates used in food products. They are discussed further in Chapter 5. Pectins occur naturally in plant food products, but gums and seaweed polysaccharides do not come from edible plant sources. They are extracted and purified and then added to food products.

Pectins are used mainly as gelling agents in jellies, jams, and other products. They also are used as stabilizers and thickeners. They are found in fruits and vegetables and they help to hold the plant cells together. Structurally, they are long-chain polymers of α-D-galacturonic acid, which is an acid derived from the simple sugar galactose. They are soluble in water and under appropriate conditions they form gels. Their structure and properties are discussed in Chapter 5.

Gums are mainly plant extracts and include gum tragacanth and guar gum. They are highly branched polysaccharides that form very viscous solutions, trapping large amounts of water within their branches. Most do not form gels because of the high level of branching. They are useful as thickeners and stabilizers, particularly in reduced-fat salad dressings and in other convenience foods.

Seaweed polysaccharides include the agars, alginates, and carrageenans. They are classified as gums, although they are able to form gels, unlike most gums. They are useful as gelling agents, thickeners, and stabilizers in foods.

Cellulose and *hemicellulose* are structural polysaccharides that provide support in plant tissues. They are not digested in the body, so they do not supply energy. However, they provide insoluble dietary fiber, which is an important part of a healthy, balanced diet.

CONCLUSION

Carbohydrates come in various shapes and sizes, from small sugar molecules to complex polymers containing thousands of simple sugar units. The digestible carbohydrates provide energy (4 cal/g), whereas the indigestible ones are an important source of dietary fiber. In addition to their nutritional value, carbohydrates are important as thickeners, stabilizers, and gelling agents. They are used in a wide spectrum of convenience foods, and without them the range of food products relished today would be greatly diminished.

GLOSSARY

Aldose: Sugar containing an aldehyde group monosaccharide—single sugar unit.

Alpha-anomer: The anomeric hydroxyl group is on the opposite face of the ring from carbon-6 (ie, the two groups point in opposite directions).

Anomeric carbon atom: The carbon atom that is part of the free carbonyl group in the straight-chain form of a sugar.

Anomers: Isomers that differ only in the orientation of the hydroxyl group on the anomeric carbon atom; there are two forms—alpha (α) and beta (β).

Beta-anomer: The anomeric hydroxyl group is on the same face of the ring as carbon-6 (ie, the two groups point in the same direction).

Carbonyl group: Contains an oxygen atom double-bonded to a carbon atom. The aldehyde group and the ketone group both can be described as a carbonyl group.

Caramelization: Decomposition of sugars at very high temperatures resulting in brown color.

Cross-planar bond: Formed when the hydroxyl groups on the carbon atoms involved in the formation of a glycosidic bond are oriented on opposite faces of the sugar rings. Cross-planar bonds occur in cellobiose and in cellulose. They also occur in pectin. They are not digested in the human digestive system.

Dextrans: Glucose polymers joined by α-1,6-glycosidic bonds. Produced by some bacteria and yeasts.

Dextrins: Glucose polymers joined by α-1,4-glycosidic bonds. Product of starch hydrolysis. Found in corn syrups.

Disaccharide: Two sugar units joined together by a glycosidic bond.

Furanose: Five-membered ring.

Glycosidic bond: Bond that links two sugar units together; it is formed between the free carbonyl group of one sugar and a hydroxyl group of another sugar; the orientation (α or β) and position (eg, 1,4) of the link must be specified.

Hydroxyl group: The–OH group on the carbon atom.

Invert sugar: An equimolar mixture of glucose and fructose, formed by hydrolysis of sucrose, either by acid and heat, or by enzymes such as invertase or sucrase.

Ketose: Sugar containing a ketone group.

Maillard reaction (Maillard browning reaction): Nonenzymatic browning reaction involving a reducing sugar and a free amino acid group on a protein.

Monosaccharide: Single sugar unit.

Oligosaccharide: Several (3–10) sugar units joined together by a glycosidic bond.

Polysaccharide: Many (hundreds or thousands of) sugar units joined together.
Pyranose: Six-membered ring.
Reducing sugar: Sugar that contains a free carbonyl group.
Reference carbon atom: The highest numbered asymmetric carbon atom; C5 in glucose and fructose.
Reference hydroxyl group: The hydroxyl group attached to the reference carbon atom.
Sugar alcohol: The result of reduction of carbonyl group to a hydroxyl group.
Supersaturated solution: Solution that contains more solute than normally could be dissolved at a particular temperature.
Trisaccharide: Three sugar units joined together by a glycosidic bond.

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CHAPTER 4

Starches in Food

INTRODUCTION

Starch is a plant polysaccharide stored in roots and seeds of plants and is in the endosperm of a grain kernel. It provides humans with energy (4 cal per gram) and is hydrolyzed to glucose, supplying the glucose that is necessary for brain and central nervous system functioning.

Starch grains, or ***granules***, contain long-chain glucose polymers and are *insoluble* in water. Unlike the small molecules of salt and sugar, the larger starch polymers do *not* form a true solution. Instead, starch granules form a *temporary suspension* when stirred in water. As *uncooked* granules, each may swell slightly as it absorbs water. However, once starch is *cooked*, the swelling is irreversible and the starch leaches out. This characteristic of starch granules enables starch to be used as a thickener.

Overall, the characteristics of a finished starch food product are determined by several factors: the source of starch, concentration of starch used in a formulation, the temperature of heating, and other components used with the starch, such as acid and sugar. There are many types of starch and modified starches. They thicken, prevent curdling, stabilize cooked salad dressings, and more.

Intermediate, shorter, chain products from starch breakdown, known as dextrins, may be used to simulate fat in salad dressings and frozen desserts. For example, wheat, potato, and tapioca maltodextrins may be used as fat replacers. They provide the viscosity and mouthfeel of fat in a food product, yet with reduced calories compared to fat.

STARCH SOURCES

Starch sources are numerous, with common ones derived from cereal grains such as wheat, corn, or rice. Wheat yields a cloudy, thick mixture, while cornstarch produces more clear mixtures such as gravies or sauces. Vegetables, roots and tubers, including the root of cassava, and potatoes frequently are used in the preparation of gluten-free foods, where wheat allergies do not permit the use of wheat as a thickener. Specialty starches are available commercially and some may be available to the consumer, purchased through specialty food stores.

Another source of starch is legumes such as soybeans or garbanzo beans. As well, sago is a powdery starch obtained from the stems and trunks of the sago palm in tropical Asia. It may be used a food thickener and fabric stiffener. Fruits also may be sources of starch. An example is the banana.

Thus, starch may come from a variety of sources. Depending on the source, starch also may have different crystalline structures.

STARCH STRUCTURE AND COMPOSITION

The starch *granules* from various grains differ in *size*, ranging from 2 to 150 microns. Their *shape* may be round or polygonal, as seen in the photomicrographs of corn, wheat, and waxy maize in Figures 4.1–4.3.

Starch is made up of two molecules, *amylose* and *amylopectin*, whose parts are connected by glycosidic linkages (see Ch. 3). ***Amylose*** molecules typically make up approximately one-quarter of starch. Amylose is a long linear chain composed of thousands of glucose units with attachment of the carbon 1 and carbon 4 of glucose units, and therefore contains α-1,4 glycosidic linkages. It forms a 3-dimensional network when molecules associate upon cooling, and is responsible for the gelation of cooked, cooled starch pastes.

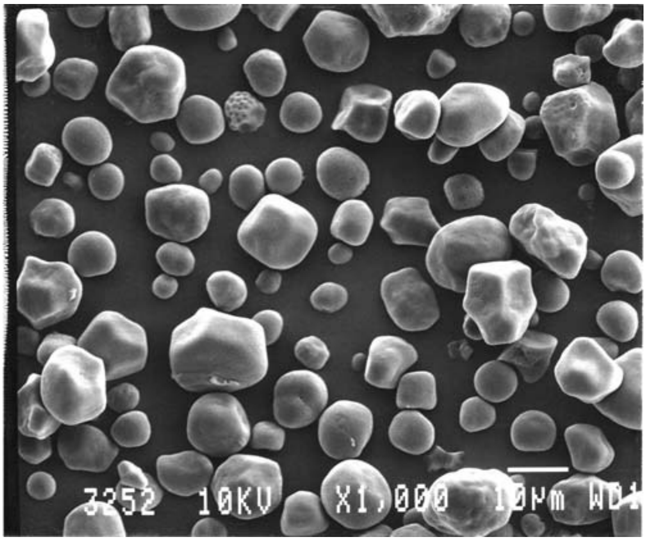


FIGURE 4.1 SEM of normal cornstarch granules (1000X) (*Source*: BeMiller, J.N., Purdue University-Whistler Center for Carbohydrate Research).

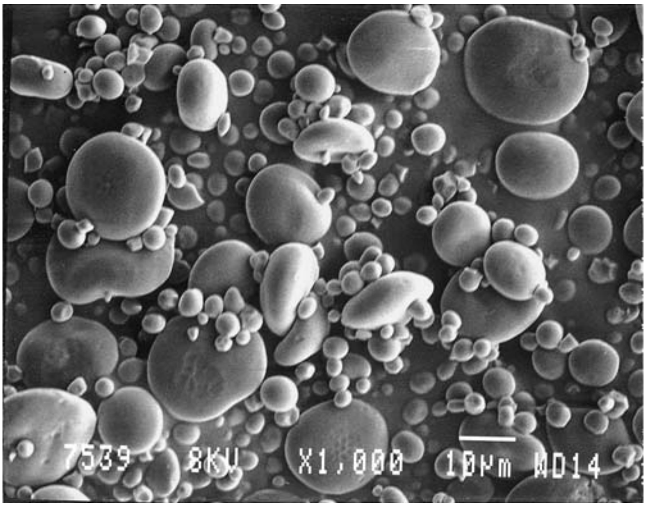


FIGURE 4.2 SEM of wheat starch granules (1000X) (*Source*: BeMiller J.N., Purdue University-Whistler Center for Carbohydrate Research).

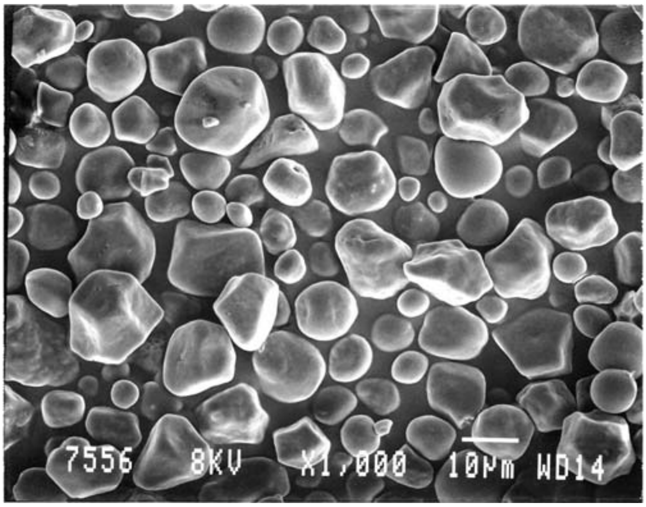


FIGURE 4.3 SEM of waxy maize starch granules (1000X) (*Source*: BeMiller J.N., Purdue University-Whistler Center for Carbohydrate Research).

While starches *high* in amylose gel, or hold their shape when molded, starches *without* amylose thicken, but do *not* gel. Examples of the amylose content of various starch sources include:

cereal grains: 26–28%
roots and tubers: 17–23%
waxy varieties of starch: 0% amylose

Amylopectin molecules (Chapter 3) constitute approximately three quarters of the polymers in a starch granule. The glucose chain of amylopectin contains α-1,4 linkages, similar to amylose; however, with α-1,6 branching at every 15–30 glucose units of the chain. There is a linkage between the carbon 1 of the glucose and carbon 6 of the branch. The chains are highly branched and bushy (but less branched than the *animal* storage form of carbohydrate, which is glycogen, *not* starch).

Starches with a high percentage of amylopectin will *thicken* a mixture but do *not* form a *gel*, because unlike amylose amylopectin molecules do not associate and form chemical linkages. The greater the amylopectin, the more viscous the starch paste and the greater the amount of amylose the stronger the gel.

GELATINIZATION PROCESS

Starch in its *uncooked* stage is insoluble in water. Thus it cannot be referred to as "going into solution" or "dissolving." It forms a temporary ***suspension*** of large particles, which are *undissolved* in the surrounding medium, and these particles will settle to the bottom of a container of liquid unless agitated. The particles may imbibe a small amount of water, but generally a suspension offers minimal change to the starch. Any uptake of water by the starch granule is reversible if starch is dried while still in the *uncooked* state.

Another feature of the *un*cooked starch molecule is that it exhibits a maltese cross formation, or ***birefringence*** on the granule when it is viewed under polarized light with an electron microscope. This is due to the fact that it is a highly ordered crystalline structure, and light is refracted in two directions (Figure 4.4)

Once cooking has begun, when the starch is heated in surrounding *water*, ***imbibition***, or the taking of water into the granule occurs. This first occurs in *less*-dense areas and subsequently in the *more* crystalline regions of the starch molecule. At this *initial* point this is still a *reversible* step in the gelatinization process. However, as heating continues, starch granules take up more water irreversibly and swell; some short chains of amylose come out of the granules. This process, known as ***gelatinization***, is responsible for the thickening of food systems. The gelatinized starch mixtures are opaque and fragile and the ordered crystalline structure of starch is lost.

As starch leaches out of swollen granules in the gelatinization process and the water–starch mixture becomes a ***sol***. A sol is a colloidal two-phase system

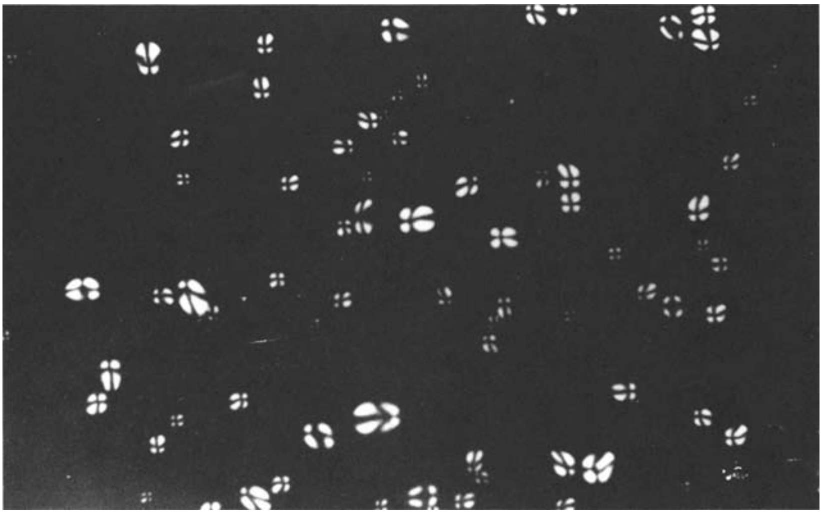


FIGURE 4.4 Photomicrograph of ungelatinized starch taken through cross-polarizers (*Source*: BeMiller, J.N., Purdue University-Whistler Center for Carbohydrate Research).

containing a liquid continuous phase and a solid dispersed phase. This solid-in-a-liquid is pourable and has a low ***viscosity*** or resistance to flow.

$$\boxed{\text{SUSPENSION} \xrightarrow[\text{heat}]{} \text{SOL}}$$

Gelatinization may be synonymous with *pasting*, although the two terms may be reported as sequential occurrences (1). Whether a separate process or the continuation of gelatinization, pasting occurs with the continued heating of gelatinized starch grains. The process involves a *loss* of the ordered crystalline structure in starch, which is observed as the *disappearance* of the maltese cross formation when starch is viewed under polarized light with an electron microscope.

The temperature at which various starches gelatinize is actually a *range* of temperatures specific to a starch. The granules within a starch will swell and thicken mixtures at slightly different temperatures, with the larger granules swelling earlier than smaller granules.

The **steps** in the gelatinization process are as follows:

- The gelatinization temperature is *reached* at approximately 140°–160° F (60°–71° C), depending upon the starch type, and is *completed* at 190–194° F (88–90° C), or higher.

- The kinetic energy of the hot water molecules breaks the hydrogen bonds between the starch molecules. Hydrogen bond interchange occurs as starch forms hydrogen bonds with water molecules instead of other starch molecules. As hydrogen bonds are formed, water is able to penetrate further into the starch granule and swelling takes place. Sufficient water must be present to enter and enlarge the starch granule.
- Diffusion of some amylose chains occurs as they leach out of the starch granules.
- Birefringence and the ordered crystalline structure of the uncooked granule is lost. Increased translucency is apparent because the refractive index of the expanded granule is close to that of water.
- Granule swelling increases as the temperature increases. The larger starch granules are the first to swell.
- Swollen granules take up more space and the mixture thickens as the enlarged granules leach amylose and possibly amylopectin.
- The starch paste continues to become thicker, more viscous, and resistant to flow as it gelatinizes.
- The final step in the gelatinization involves the necessity of cooking the gelatinized starch mix—gravy, pie filling, and so forth—for 5 minutes or longer to develop flavor. Unnecessary overstirring thins the cooked starch mixture because the swollen starch granules implode, rupture, and lose some of the liquid held inside the enlarged granule.

FACTORS REQUIRING CONTROL IN GELATINIZATION

Several factors must be controlled during gelatinization in order to produce a high-quality gelatinized starch mixture. Starches that are not *thoroughly* gelatinized *cannot* produce viscous pastes or strong gels.

These factors include the following:

Agitation: Agitation, or stirring both initially and throughout the gelatinization process, enables granules of starch to swell independently of one another and creates a more uniform mixture without lumps. However, as previously mentioned, excessive agitation after gelatinization is complete may rupture granules and consequently thin starch mixtures.

Acid: Acid hydrolysis during cooking of starch granules results in fragmentation and the formation of ***dextrins*** or short-chain polymers. Hydrolysis of the starch molecule results in less water absorption by the starch granule, thus a thinner *hot* paste and less firm *cooled* product. Therefore, the late addition of acid to a starch mixture is best, after starch has been gelatinized and begun to thicken. Acid is frequently added to starch sauces in the form of vinegar, tomatoes, fruit, or citrus juice.

Enzymes: Starch may be hydrolyzed by the starch-splitting enzymes α-amylase, beta-amylase and beta-glucoamylase.

Endoenzymes such as α-amylase act anywhere on the starch chain and undamaged starch grains to degrade starch. The hydrolysis products of β-amylase are glucose, maltose, and dextrins, depending on the extent of hydrolysis that takes place, and this may be desirable in commercial breadmaking.

The *exoenzyme* β-amylase acts on α-1,4 glycosidic linkages from the nonreducing end and on damaged amylose or amylopectin chains. This further hydrolyzes starch two glucose units at a time, thus producing maltose.

The beta-amylase cannot hydrolyze starch beyond the branch points of amylopectin. The enzyme β-glucoamylase hydrolyses α-1,4 link produces glucose and slowly hydrolyzes α-1,6 linkages in starch.

Fat, and proteins: The presence of fat and protein (such as in meat drippings used to produce gravy) initially coats or ***adsorbs*** to the surface of the starch granules, causing a delay in hydration and viscosity. Fat "waterproofs" the starch granules so that water does not easily penetrate during the gelatinization process. Thus, there is less granular swelling and less amylose exiting from the granule, resulting in a decreased viscosity of the starch paste and decreased gel strength.

Sugar: The addition of just moderate amounts of sugar, especially the disaccharides sucrose and lactose from milk, decreases starch paste viscosity and the firmness of the cooked and cooled starch product. It competes with the starch for water, and thus delays the absorption of water by starch granules. This prevents a speedy or complete swelling of the starch granule. Sugar also elevates the temperature required for gelatinization to occur.

As with acid addition, timing of sugar addition is significant. For a thicker mixture and gel, it is advised that a *partial* addition of sugar before the starch thickens and the remainder added later is best. Thus there is less sugar to compete with granule water absorption than if all of the sugar is added at the beginning of cooking.

If *both* acid and sugar are added to a starch mixture, there is less swelling due to the presence of sugar that competes with starch for water and there is less hydrolysis from acid on the granule.

Salt: Raises the temperature at which a starch mixture thickens.

Temperature: As previously mentioned, there is a range of temperatures, 190–194° F (88–90° C), that need to be met for gelatinization to occur. The *completion* is up to 203° F (95° C), although starches vary in their gelatinization temperature.

Length of heating: As the heating time is lengthened, the finished mixture may be *thinner* due to possible overstirring and rupturing of enlarged granules. Alternatively, cooking for a long time in an uncovered double boiler may *evaporate* the water that *otherwise* would thin the mixture.

Type of heat: *Moist heat* is necessary for gelatinization to occur. *Dry heat* causes the starch to hydrolyze, forming shorter-chain dextrins. Dry heat creates "browned" flour that imparts a slightly toasted flavor and brown color to a food mixture. This browning effect may be desired in many recipes.

Rate of heating: In general, the faster a starch–water dispersion is heated, the thicker it will be at an identical end point temperature.

It can be seen that many factors—many "ifs"—must be controlled in gelatinization. For example, a three-dimensional starch structure forms IF gelatinization has occurred correctly; IF the starch is the correct type; IF the concentration is sufficient; IF the heat is correctly applied; IF inclusion of added substances is properly timed, and so forth!

The viscosity of a starch and water mixture is recorded on a moving graph as the mixture is tested and stirred (Figure 4.5). The recording instrument portrays the thickness of starch mixtures during heating, gelatinization, and cooling. It may be used in order to show the effects of α-amylase on starch mixtures or the thickness of various starches at different times and temperatures. Evidence of dextrinization may be seen.

Further discussion of specific times and temperatures of when various starches thicken or gel may be observed by reading data from a recording

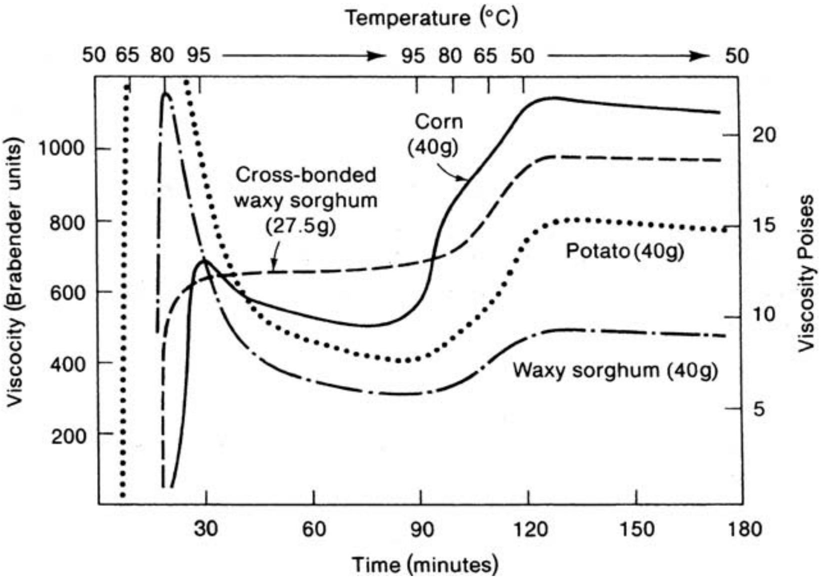
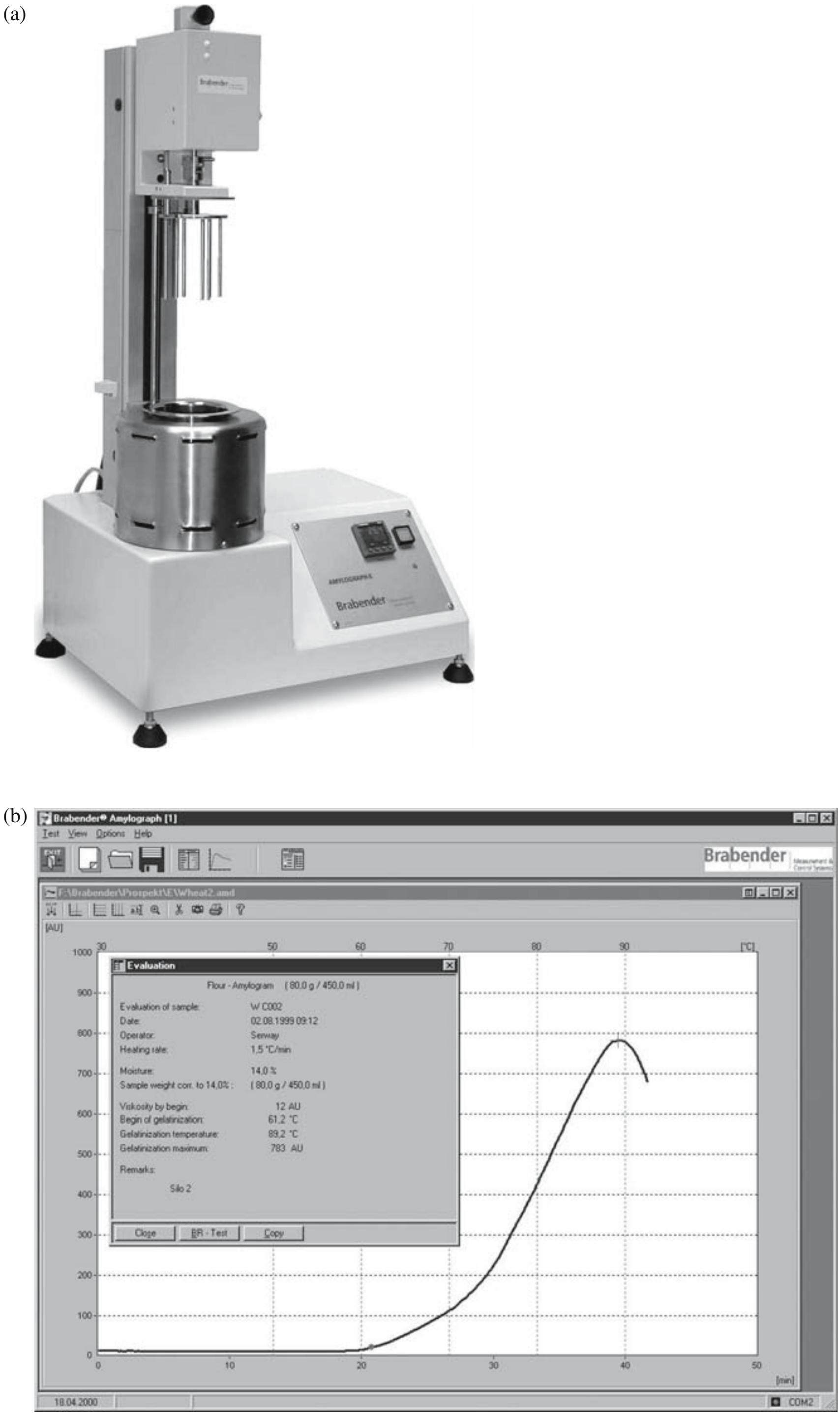


FIGURE 4.5 Graph of the thickening of various starches (*Source*: Schoch T.J. Starches in foods. In: *Carbohydrates Their Roles*. Schultz HW, Cain RF, Wrolstad RW, eds. Westport, CT: AVI Publishing Company, 1969. With permission).



Evaluation

Flour - Amylogram (80,0 g / 450,0 ml)

Evaluation of sample: W C002
Date: 02.08.1999 09:12
Operator: Serway
Heating rate: 1,5 °C/min

Moisture: 14,0 %
Sample weight corr. to 14,0% : (80,0 g / 450,0 ml)

Viskosity by begin: 12 AU
Begin of gelatinization: 61,2 °C
Gelatinization temperature: 89,2 °C
Gelatinization maximum: 783 AU

Remarks:

Silo 2

FIGURE 4.6 Brabender Amylograph and Brabender amylogram (*Source*: C.W. Brabender Instruments, Inc.).

instrument or recording viscometer (Figure 4.6). As illustrated in the graph in Figure 4.5, *root* starches such as potato and tapioca and *waxy cereal* starches thicken earlier and at lower temperatures than cereal starches.

GELATION OR SETTING OF GELATINIZED STARCH PASTES DURING COOLING

Amylose

Beyond the previously discussed process of gelatinization, there are further changes in the amylose component of starch pastes during *cooling*. For example, the amylose "sets" and forms a ***gel*** upon cooling, a process referred to as ***gelation***. It forms a colloidal, elastic, and solid, three-dimensional, two-phase system with a *solid* continuous phase of amylose polymers holding a *liquid* dispersed phase. This is in contrast to the ***sol*** it was beforehand.

The reason that the gel network forms is due to the fact that as the mixture cooled, energy is reduced. Subsequently, intermittent hydrogen cross bonds form among *amylose* and reassociate at random intervals of the amylose molecule, forming a *gel*.

Amylopectin

On the other hand, the highly branched *amylopectin* molecules do *not* readily form bonds or a gel. Rather, amylopectin exhibits *less* tendency to reassociate or revert to a more crystalline structure than amylose. It remains a sol; however, it forms a *thick* sol upon cooling as shown below. This may be desirable in food items such as pie fillings.

$$\text{SUSPENSION} \xrightarrow[\text{heat}]{\text{imbibition}} \overset{\text{maximum gelatinization}}{\text{SOL}} \xrightarrow[\text{cool}]{\text{gelation}} \text{GEL (or a thick sol)}$$

Gels

Starches may be selected for use based on their gelling potential as identified in the following list:

Forms Gel	**Does Not Form Gel**
Cornstarch	Waxy cereals
Wheat starch	Tapioca
Wheat flour	

If gels are formed, mixtures are nonpourable and of high viscosity. Gelling requires a quantity of two times the amount of flour as cornstarch because an equal amount of flour contains additional nonstarch components such as protein.

RETROGRADATION

Retrogradation refers to the occurrence where starch reverts or retrogrades to a more crystalline structure upon cooling. Both amylose and amylopectin may participate in a textural change that makes them somewhat more "gritty" with time. Retrogradation is more likely in *high amylose* starches. It is noted in baked products that become *"stale,"* no longer *"fresh"* tasting or handling (a "fresh" baked good indicates that the starch is still in existence as a gel form). It also is observed in leftover, long-grain rice. Due to its high amylose content, leftover rice gets hard.

Retrogradation Facts:

- If gel has been formed improperly, the resulting amylose structures are fragile, readily losing entrapped water.
- Amylose retrogrades and recrystallizes.
- When gel is exposed to the effects of freeze–thaw cycles, the water is frozen and thawed. Water created from melted ice crystals is not able to reassociate with the starch, and water loss becomes apparent.

Included below are a few baking examples of retrogradration from the literature. They are used to better clarify the term.

- "In baking, the starch present in bread doughs and batters becomes gelatinized. During this process the starch goes from an ordered, crystalline state to a disordered, amorphous state. Upon cooling the disordered starch state begins to re-order (or retrograde), returning the starch back to its more rigid crystalline state, resulting in the firming of crumb texture in baked goods. Starch retrogradation is a time and temperature dependent process." Available from: Tessier, J. Increasing Shelf-Life without Preservatives (Bakers' Journal: July 2001) http://www.gftc.ca/articles/2001/baker07.cfm
- "When the starch stays as a gel, a product is softer, and we say it is "fresh." When the starch regains its crystalline form, the product becomes firmer, and we say it is "stale." The technical term for this is starch retrogradation." Available from: Ingredients Starch and Modified Starch http://sci-toys.com/ingredients/starch.html
- "Staling as a result of changes in the starch component (ie, a change in the amylose and amylopectin starch molecules) of the bakery product is called starch retrogradation. Starch retrogradation begins as soon as baking is complete and the product begins to cool. Amylose retrogradation is mostly complete by the time the product has cooled to room temperature.

Amylopectin retrogradation requires more time than amylose retrogradation, and as a result is the primary factor resulting in staling. During the staling period, the amylopectin molecules revert back to their original firm state as rigid crystalline granules. As a result, the baked product loses moisture in the crumb, becoming firmer and less elastic." Available from: Nadia Brunello-Rimando. Bakers' Journal—Voice of the Canadian Baking Industry. May 2004. http://www.gftc.ca/articles/2004/baker05.cfm

SYNERESIS

Still another change following *gelatinization* and caused by *gelation* may occur. The gel may lose water. If cooled undisturbed, the gels remain strong, yet reassociation may be accompanied by the unacceptable water loss or *syneresis*. ***Syneresis*** or "weeping" is water freed from a cooked, cooled starch gel caused by retrogradation. It is the separation of a liquid from a gel upon standing.

As a cooked, cooled starch gel stands, the gel ages. Further association of amylose occurs and the gel contracts, causing both water loss and shrinkage to become apparent. To control syneresis, modified starches (see section Modified Starches) or starches containing only non-gelling amylopectin are used in commercial products.

"Research has well established that the cooling conditions will impact the strength of the gel. Generally, if cooled too fast, the amylose will not have time to form the vital micelles necessary for the three-dimensional structure. If cooled too slowly, the amylose fractions will have a chance to align too much and become too close together and the liquid portion will not be trapped in the micelles. In both instances there will be weeping and syneresis." (Oregon State University) Available from: http://food.oregonstate.edu/learn/starch.html

SEPARATING AGENTS AND LUMP FORMATION

A problem in the preparation of starch-thickened mixtures is the undesirable formation of lumps which is due to the unequal swelling or "clumping" together of individual starch granules. The granules must be allowed to swell independently; thus it becomes important to "separate" the granules with a separating agent.

For product success, one of the three ***separating agents*** such as fat, cold water, and sugar must be used. They should be added to *just* the starch/flour ingredient in order to physically *separate* the grains *prior* to its addition to a recipe. Use of these agents produce a smooth textured mixture.

- **Fat:** *Fat* is a separating agent. When stirred into the flour, fat forms a film around the individual starch granule allowing each granule to swell independently of other granules. Thus, a *lump-free* sauce or gravy is obtained when liquid is added and cooking occurs. Oftentimes a *roux* is made: flour is browned and then separated by agitation with liquid fat during heating.

A roux may range in color from light brown to almost black (Cajun cooking). As a starch is heated and becomes darker, the starch progressively loses its thickening ability as it undergoes dextrinization from heating. An added benefit of adding flour to *hot* meat fat drippings is that α-amylase (which thins) is destroyed.

- **Cold water:** *Cold water* may be used to physically separate starch granules. When mixed with insoluble starch, water puts starch granules in a suspension known as a "*slurry*." The cold water–starch suspension is then slowly mixed into the hot liquid for thickening.

  Cold water as a separating agent may be desirable if the product is to remain fat-free or sugar-free. *Hot* water is not a successful separating agent as hot water partially gelatinizes the starch.
- **Sugar:** *Sugar* is a common separating agent used for a sweetened mixture. It is mixed with starch, prior to incorporation into the liquid, so that starch granules remain physically separate to allow individual swelling.

Once starch is separated so that the granules do not "clump together," forming lumps, the separated starch mixture is added to the other recipe ingredients. Sauces must be heated slowly and/or **stirred constantly** in order to be free of lumps. Extensive or harsh stirring after maximum gelatinization has occurred will rupture starch granules, causing the mixture to be thin.

CULINARY ALERT! Many cookbook recipes do not specify the use/proper use of a separating agent and the result is a mixture with lumps. The choice of which separating agent to use is dependent on the desired end product, eg sweetened, fat free, and so forth.

MODIFIED STARCHES

Natural starches may be ***modified*** chemically to produce physical changes that contribute to shelf stability, appearance, convenience, and performance in food preparation. Some "natural" starches are *not* modified chemically which may be a "plus" for concerned consumers and processors. Some examples of modified starches used in food manufacturing are described in the following text.

Pregelatinized starch is an instant starch that has been gelatinized and then dried. It subsequently swells in liquid without the application of heat. Pregelatinized starch appears in many foods, including instant pudding mixes. Some properties of a pregelatinized starch include the following:

- dispersible in cold water; it can thicken without heat being applied
- can be cooked and dried, yet is able to reabsorb a lot of water in preparation without cooking the food (instant pudding)
- undergoes irreversible change and can not return to its original ungelatinized condition after treatment

- a greater weight of starch is required to thicken a liquid because some rupturing and loss of starch granule contents occurred during gelatinization and drying

Cold water-swelling (CWS) starch is an instant starch that remains as an *intact granule*. It offers convenience, stability, clarity, and texture. Cold water-swelling starches may be gelling or nongelling. They may be used in no-cook or cold-process salad dressings, providing the thick, creamy mouthfeel in no-fat salad dressings.

Cross-linked starches are those that undergo a molecular reaction at selected hydroxyl (-OH) groups of two adjoining, intact, starch molecules. The purpose of cross-linking is to enable the starch to withstand such conditions as low pH, high shear, or high temperatures. The cross-linked starch becomes less fragile and more resistant to rupture than the original unmodified starch.

Although it is more tolerant of *high* temperatures, it is *not* more tolerant of *cold* temperatures. These starches are used in many foods, especially acid food products such as pizza sauce or barbecue sauce because the modified starch is *more acid resistant* than an unmodified starch. As a result of cross-linking, a starch swells less and is less thick.

Stabilized (substituted) starches are used in frozen foods and other foods stored at cold temperature in order to prevent gelling and subsequent syneresis. These starches prevent molecular associations and cause ionic repulsion. The stabilized starch produces pastes able to withstand several freeze–thaw cycles before syneresis occurs. This is of value to the frozen food industry and also to foods such as sauces and gravies stored at cold temperatures.

Stabilized starches are *not* appropriate for foods that require prolonged *heating*. However, starches may be modified by a combination of both cross-linking and stabilization treatments. Such modification ensures that the starches are acid, heat, and freeze–thaw stable. Stabilized starches have a wide range of uses in food products.

Acid modified starch is starch that is subject to treatment in an acid slurry. A raw starch and dilute acid are heated to temperatures less than the gelatinization temperature. Once the starch is mixed into a food product, it appears less viscous in *hot* form, but forms a strong gel upon *cooling*. More about modified starches as follows: http://food.oregonstate.edu/learn/starch.html.

Nonfood uses for modified starches include glue in cardboard manufacture and glue on postage stamps.

WAXY STARCHES

Waxy starches are derived from some natural strains of barley, corn, rice, and sorghum. They do *not* contain amylose, begin to thicken at *lower* temperatures, become *less* thick, and undergo *less* retrogradation than nonwaxy varieties. *Waxy* cornstarch, for example, does not have the same gel forming properties as cornstarch. It contains *no* gel producing *amylose*, but rather *amylopectin*.

• Waxy cornstarch:	contains NO amylose, is all amylopectin, and does NOT gel
• Ordinary cornstarch:	contains 27% amylose and forms a gel
• High amylose cornstarch:	contains 55% amylose and forms a gel

Waxy varieties of starch are commonly used in the preparation of pie fillings to *thicken* but not gel. They also may be cross-linked for better function.

Starch Uses in Food Systems

Starches are very versatile and oftentimes inexpensive. They may be introduced into foods primarily because of their *thickening* ability. For example, cooked or instant potatoes or pureed cooked rice may be useful as thickeners. A white sauce may be added during the preparation of a tomato and milk-based soup in order to thicken and stabilize–control milk protein precipitation from the tomato acid. Starch also may be useful as a water binder and gelling agent.

Another use of starch is as a *fat replacer* in food systems. Molecularly, the amylose chains form helical or spherical shapes, holding water and providing bulk. This confers the satisfying "mouthfeel" attributes on starch. Intermediate-length polymers of D-glucose, called ***maltodextrins*** are formed from the hydrolysis of starches such as tapioca, potato, and wheat. Maltodextrins simulate the viscosity and mouthfeel of fats/oils and are used to reduce the fat content of some foods.

With the use of ordinary cross-breeding procedures, new starches are being discovered that have various applications in food systems. Baking, microwave cakes, frozen sauces, fat replacers, breadings, snacks, and gelled candies are some of the uses of starch (2). For example, **pea starch** may offer an alternative to other modified starches used in the food industry as it provides a very high viscosity *immediately* upon agitation. It is available in pregelatinized form for use in cold processed products such as dessert creams, dressings, instant soups, and sauces (3).

New food starches and their uses are continually being developed. Food starches are commercially manufactured and available for use in products such as baked food, beverages, canned, frozen and glassed foods, confections, dairy products, dry goods, meat products, and snack foods (4).

One new food application of starch granules is their use as *flavor carriers*. Using normal processing methods, small starch granules may be mixed with gelatin or water-soluble polysaccharides and then spray dried, forming a sphere. ***Spherical aggregates*** of starch granules contain open porous spaces within the chain which can be filled and used to transport material such as flavors, essences, and other aroma compounds. Spherical aggregate carriers potentially offer time-release of flavors or essences and protection of these flavors from oxidation (5).

CULINARY ALERT! A starch chosen for use in food systems may involve a choice by habit or convenience. Consumers actually may use less than the best because "it's what mom always used, so I'll use it too," or "it's here in the kitchen, so I'll use it!"

COOKING WITH STARCH

Some of the applications of cooking with starch appear below. Cooking with the appropriate starch in the proper concentration is crucial to the success of any starch-thickened product.

Appearance

The appearance of a cooked, cooled starch mixture is influenced by the choice of starch. For example, *cereal* starches in general produce *cloudy,* thickened mixture upon cooling. Within the group of cereals, *flour* produces a *more* cloudy thickened mixture than cornstarch because the wheat flour contains additional nonstarch ingredients not present in cornstarch. A *clear gel* is produced using cornstarch.

A *clear, thickened mixture* is also produced by other nongelling starch sources such as arrowroot. Nongelling may be a desirable feature of pie fillings.

Use of a Double Boiler

Cooking over boiling water (such as with a double boiler for household preparation) promotes temperature control and even gelatinization. A disadvantage of this cooking method is that it requires cooking for a longer time period to reach the thickening stage than a direct heat cooking method.

Tempering

Tempering involves the technique of *slowly* adding small amounts of hot starch to eggs in a recipe to gradually raise the temperature, thus slowly exposing eggs to heat without danger of coagulation. In this manner, the eggs do not curdle and produce an unacceptable consistency. To achieve the desired consistency and texture of a recipe containing hot starch *and* raw eggs (in sauces, cream puffs, etc.), the process of *tempering* is used.

White Sauce

White sauces have widespread applications in cooking. The *concentration* of starch used in a formulation varies. For example, a white sauce of flour, fat, and milk may be thickened to various consistencies, for croquettes, sauces, and so forth. The concentration of flour may be as follows:

thin: 1 tablespoon of flour/cup of liquid
medium: 2 tablespoons of flour/cup of liquid
thick: 3 tablespoons of flour/cup of liquid

Liquid

The use of liquid type varies in starch mixtures. *Water or fruit juice* is incorporated into some foods dictated by need for clarity or flavor. Milk usually is used in a starch-thickened sauce such as white sauce. Milk easily curdles at high temperatures; however, it may be less likely to curdle when first thickened with flour.

CULINARY ALERT! Flourless sauces are thickened by reduction of the stock/liquid. Portions of the starchy ingredients of a soup recipe may be pureed and then added back to the soup in order thicken and flavor it.

NUTRITIVE VALUE OF STARCH

Starch is a complex carbohydrate containing 4 calories per gram and traces of protein and fat. Short-chain maltodextrins derived from the hydrolysis starch may be used in foods to partially replace fat. Maltodextrins simulate the taste of fat and offer less calories per gram than the 9 calories per gram in fat.

Not all starch is capable of carrying calories or being digested. A *resistant starch* is dietary fiber, with an example being whole cooked beans. Resistant starches offer benefits to the colon, namely, “roughage.” Also, intestinal bacterial flora use fiber, producing vitamins such as vitamin K.

Whole grains that are *ground* to make flour are different than the whole grain from which they came. For example, they have a higher *glycemic index* than *unground* grains. This is due to the ease of absorbing the starch into the blood as sugars.

Special nutritional needs may require a dietary restriction of wheat may lead to use of non-wheat starches in those individuals following gluten-free diets. Some alternatives to wheat are corn, potato, or rice starch. Packages of potato “flour” indicate that the contents are solely potato *starch* (6).

CONCLUSION

Starch is a plant polysaccharide that is the storage form of carbohydrate in roots, seeds, and tubers. It may be derived from cereals such as corn, wheat, rice, or oats; legumes such as soybeans; or from vegetable roots and tubers such as potatoes or arrowroot. In its uncooked stage, starch is insoluble in water. As it is heated and undergoes gelatinization, factors such as acid, agitation, use of enzymes, fat, proteins, sugar, and temperature require control. A separating agent prevents lumps in a starch mixture.

The source of starch and its concentration determine the thickening, gelling, retrogradation, and clarity of the finished product. Flour and cornstarch may be used to form gels; waxy varieties of starch do not gel. Syneresis may occur as the cooked, cooled starch mixture ages. Modification of starch granules allows starches to be used successfully in a variety of food applications. Starch may be added to foods in order to provide thickening or product stability or potentially to carry flavors.

GLOSSARY

Adsorb: Surface adherence of gas, liquids, or solids onto a solid.

Amylose: Long, linear chain composed of thousands of glucose molecules joined by an α-1,4-gycosidic linkage.

Amylopectin: Branched chains of glucose units joined by α-1,4 linkages, with α-1,6 branching occurring every 15–30 units.

Birefringence: A Maltese cross appearance on each uncooked crystalline starch granule when viewed under a polarizing microscope due to light refraction in two directions.

Dextrin: Glucose polymers; a product of the early stages of starch hydrolysis.

Gel: Elastic solid formed upon cooling of a gelatinized starch paste; a two-phase system that contains a solid continuous phase and a liquid dispersed phase.

Gelatinization: Starch granules take up water and swell irreversibly upon heating, and the organized granular pattern is disrupted.

Gelation: Formation of a gel upon cooling of a gelatinized starch paste.

Granule: Starch grain of long-chain glucose polymers in an organized pattern; granule shape is particular to each starch type.

Imbibition: Starch granules taking up water and swelling as it is exposed to moist heat.

Maltodextrin: Starch hydrolysis derivative that may be used to simulate fat in formulations.

Modified starch: Specific chemical modification of natural starches to physically create properties that contribute to shelf stability, appearance, convenience, and performance in food preparation.

Retrogradation: Reverting back or reassociation of amylose as the gelatinized starch once again forms a more crystalline structure upon cooling.

Separating agent: Prevents lump formation in a starch mixture. Physically separates starch grains and allows their individual swelling.

Sol: A two-phase system with a solid dispersed in a liquid continuous phase.

Spherical aggregate: Open, porous starch granules with spaces that can be filled and used to transport materials such as flavor, essences, and other compounds.

Starch: Carbohydrate made up of two molecules—amylose and amylopectin.

Suspension: Large particles undissolved in the surrounding medium. Particles are too large to form a solution or a sol upon heating.

Syneresis: “Weeping” or water loss from a cooked, cooled gel due to excessive retrogradation or improper gel formation.

Viscosity: Resistance to flow of a liquid when force is applied. A measure of how easily a liquid will flow. Thin liquids have a low viscosity. Thick liquids or gels have a high viscosity and flow slowly.

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CHAPTER 5

Pectins and Gums

INTRODUCTION

Pectins and gums are important polysaccharides in foods because of their functional properties. They are widely used as gelling agents, thickeners, and stabilizers. They are constituents of plant tissue and are large, complex molecules whose exact nature is not certain. However, enough is known to understand some of their properties and to make use of their functional properties to produce convenience and special texture foods.

PECTIC SUBSTANCES

Pectic substances including protopectin, pectinic acid, and pectic acid are an important constituent of plant tissue and are found mainly in the primary cell wall. They also occur between cell walls, where they act as intercellular cement. Although their exact nature is not clear, they can be considered as linear polymers of D-galacturonic acid joined by α-1,4-glycosidic linkages, as shown in Figure 5.1. Some of the acid or carboxyl (COOH) groups along the chain are esterified with methanol (CH_3OH) as shown.

Each glycosidic linkage is a ***cross-planar*** bond, because it is formed by reaction of one hydroxyl group located above the plane of the first ring with another hydroxyl group located below the plane of the second ring. The configuration of these bonds causes twisting of the molecule, and the resulting polymer can be linkened to a twisted ribbon. Cross-planar bonds are not readily digested in the human digestive tract, and so pectins are classified as soluble fiber.

Pectic substances may be grouped into one of the three categories depending on the number of methyl ester groups attached to the polymer. ***Protopectin*** is found in immature fruits and is a high-molecular-weight methylated galacturonic acid polymer. It is insoluble in water but can be converted to water-dispersible pectin by heating in boiling water. It cannot form gels. ***Pectinic acid***

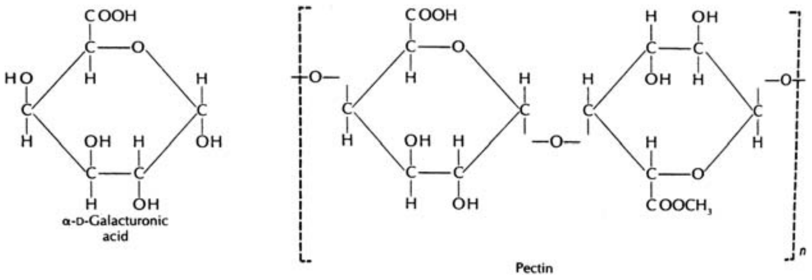

FIGURE 5.1 Basic structure of pectic substances.

is a methylated form of galacturonic acid that is formed by enzymatic hydrolysis of protopectin as a fruit ripens. High-molecular-weight pectinic acids are known as pectins. Pectinic acids are dispersible in water and can form gels. ***Pectic acid*** is a shorter-chain derivative of pectinic acid that is formed as fruit overripens. Enzymes, such as polygalacturonase and pectinesterase, cause depolymerization and demethylation of the pectinic acid, respectively. Complete demethylation yields pectic acid, which is incapable of gel formation.

PECTIC SUBSTANCES

Protopectin: methylated galacturonic acid polymer found in immature fruits
Pectinic acid: methylated galacturonic acid polymer; includes pectins
Pectic acid: short-chain demethylated derivative of pectinic acid found in overripe fruits

Pectins

Pectins are high-molecular-weight pectinic acids and are dispersible in water. Some of the carboxyl groups along the galacturonic acid chain are esterified with methanol. The degree of esterification in unmodified pectins ranges from about 60% in apple pulp to about 10% in strawberries. (Pectins can be deliberately deesterified during extraction or processing.) According to the degree of esterification, pectins are classified as ***high methoxyl*** or ***low methoxyl*** pectins. The two groups have different properties and gel under different conditions.

Low-methoxyl pectins. Low-methoxyl pectins contain mostly free carboxyl groups. In fact, only 20–40% of the carboxyl groups are esterified. Therefore, most of them are available to form cross-links with divalent ions such as calcium, as shown in Figure 5.2.

If sufficient cross-links are formed, a three-dimensional network can be obtained that traps liquid, forming a gel. Low-methoxyl pectins thus can form gels in the presence of divalent ions without the need for sugar or acid.

High-methoxyl pectins. High-methoxyl pectins contain a high proportion (usually 50–58%) of esterified carboxyl groups. Most of the acid groups therefore

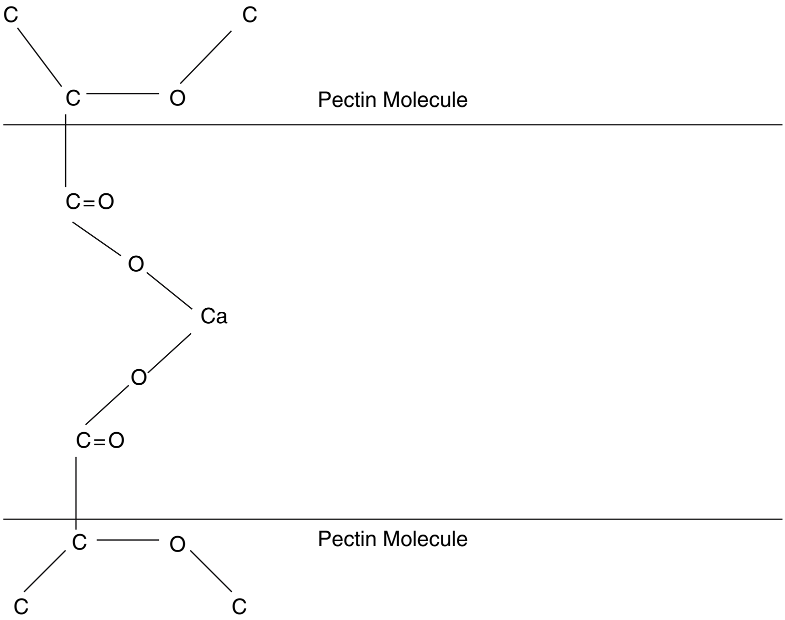

FIGURE 5.2 Cross-links in low-methoxyl pectin.

are not available to form cross-links with divalent ions, so these pectins do not form gels. However, they can be made to gel with the addition of sugar and acid. It is the high-methoxyl pectins that are commonly used to form pectin jellies.

Pectin Gel Formation

A pectin gel consists mainly of water held in a three-dimensional network of pectin molecules. Pectin is dispersible in water and forms a ***sol*** (solid dispersed in liquid continuous phase), but under the right conditions, it can be converted into a ***gel*** (liquid dispersed in solid continuous phase). This occurs when the pectin molecules interact with each other at specific points. It is not easy to form pectin gels; it requires a delicate balance of pectin, water, sugar, and acid.

Pectin is hydrophilic (water loving) due to the large number of polar hydroxyl groups and charged carboxyl groups on the molecule. When pectin is dispersed in ***water***, some of the acid groups ionize and water binds to both the charged and polar groups on the molecules. The negative charge on the pectin molecules, coupled with their attraction for water, keeps them apart so that they form a stable sol.

To form a gel, the forces keeping the pectin molecules apart must be reduced so that they can interact with each other at specific points, trapping water within the resulting three-dimensional network. In other words, the attraction of the pectin molecules for water must be ***decreased*** and the attraction of the pectin molecules for each other must be ***increased***. This can be achieved by addition of sugar and acid.

Sugar competes for water, thus making less water available to associate with the pectin molecules. This reduces the attractive forces between the pectin and water molecules.

Acid adds hydrogen ions, reducing the pH. (The pH must be below 3.5 for a gel to form.) Carboxylic acids contain a ***carboxyl group*** (COOH), are weak acids, and are not fully ionized in solution; the un-ionized form of the acid exists in equilibrium with the ionized form.

$$\boxed{-COOH + H_2O \leftrightharpoons -COO^- + H_3O^+}$$

When hydrogen ions are added, they react with some of the ionized carboxyl groups to form undissociated acid groups. In other words, the equilibrium is shifted to the left and more of the carboxylic acid is present in the un-ionized form. Thus, when hydrogen ions are added to pectin, the ionization of the acid groups is depressed and the charge on the pectin molecules is reduced. As a result, the pectin molecules no longer repel each other.

In fact, there is an attractive force between the molecules and they align and interact at specific regions along each polymer chain to form a three-dimensional network. These regions of interaction are called ***junction zones***, shown diagrammatically in Figure 5.3. However, there also are regions of the pectin chains that are not involved in junction zones because they are unable to interact with each other. These regions form pockets or spaces between the junction zones that are able to entrap water. Hence, a gel is formed, with water trapped in the pockets of the three-dimensional pectin network.

Exactly how the junction zones form is not certain, but hydrogen bonds are thought to play an important role. The ***steric fit*** of the molecules (in other words, their ability to fit together in space) also is important. Pectin molecules contain minor components such as rhamnose and other neutral sugars that are bound to the main galacturonic acid chain by 1-2-glycosidic links. These sugars cause branches or kinks in the molecules and make it difficult for them to align and interact to form junction zones. However, there are regions of the pectin chains that do not contain these neutral sugars and it is these regions that are thought to form the junction zones.

High-methoxyl pectins form gels in this way. Low-methoxyl pectins require divalent ions to gel and intermediate pectins require sugar, acid, and divalent ions to gel.

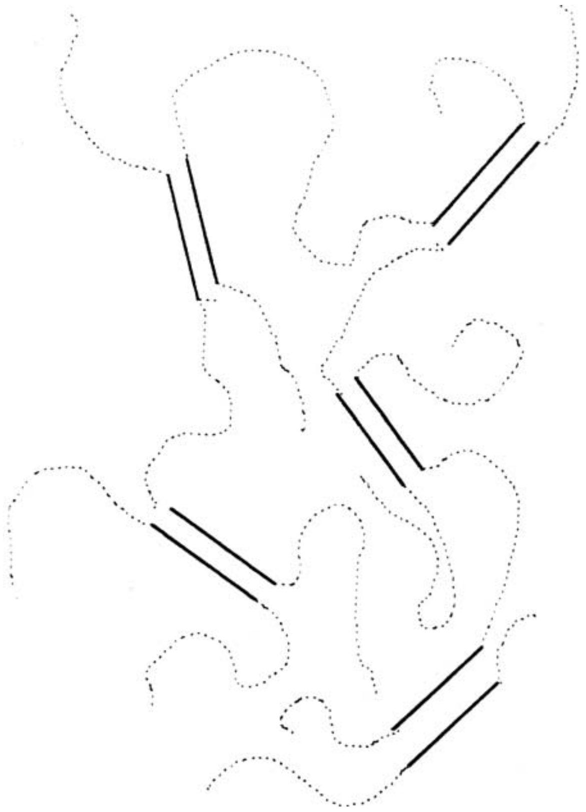

FIGURE 5.3 Junction zones in a pectin gel. Generalized two-dimensional view. Regions of the polymer chain involved in junction zones are shown as —. The other regions of the chain are shown as . . . . Water is entrapped in the spaces between the chains. Adapted from Coultate, 1989 (4).

Pectin Sources

Pectins with a high-molecular weight and a high proportion of methyl ester groups have the best jelly-forming ability. The pectin content of fruits is variable and depends not only on the type of fruit but also on its maturity or ripeness. If jellies or jams are made at home, it is best to add commercial pectin to ensure that there is sufficient pectin to form a gel. Purified pectin is made from apple cores and skins (apple pomace) and from the white inner skin (albedo) of citrus fruits. It is available in either liquid or granular form. The granular products have a longer shelf life than the liquids. Low-methoxyl pectin can be obtained by demethylating pectin with enzymes, acid, or alkali until it is 20–40% esterified (1). Because these pectins gel with divalent ions and need no sugar, they can be used commercially for the production of low-calorie jams, jellies, or desserts. They also have been introduced to the retail market so that such low-calorie products may be made at home.

PECTIN GEL FORMATION

*In a pectin **sol***

- **water** binds to ionic and polar groups on pectin
- **pectin** molecules are negatively charged and hydrated, therefore they do not interact with each other

*To form a pectin **gel***

- attraction of pectin molecules for water must be decreased
- attraction of pectin molecules for each other must be increased

This is achieved with

- **sugar**
    - competes for water
    - decreases pectin–water attraction
- **acid**
    - adds hydrogen ions
    - depresses ionization of pectin
    - reduces the charge on the pectin molecules
    - increases pectin–pectin attraction
- **pectin**
    - interacts at junction zones forming a three-dimensional network
    - pectin becomes the continuous phase
- **water**
    - is trapped in pockets within the gel network
    - water becomes the disperse phase

Some Principles of Making Jelly

This book does not attempt to describe the practical aspect of making jellies. For such information, the reader is referred to consumer information publications or to books by authors such as Charley (2) or Penfield and Campbell (3). The intention is to highlight some of the more important scientific principles of jelly-making.

To make jelly, fruit juice (which is a source of water and acid), pectin, and sucrose are combined in a suitable pan and heated until the mixture boils. The temperature and boiling time are monitored and boiling is continued until the desired temperature is reached.

As boiling continues, water evaporates, the concentration of sucrose increases, and the boiling point of the jelly also increases. Therefore, the boiling point can be used as an index of sucrose concentration. By measuring the temperature of the boiling jelly, it can be determined when sufficient water has been removed to give the desired sucrose concentration in the final jelly. However, all solutes increase the boiling point of water, so it is important to allow for the effect of any additional ingredients on the boiling point; a pure sucrose solution may boil at a lower temperature than a jelly mix containing the same concentration of sucrose. In other words, a boiling jelly may contain less sucrose than expected if the effects of the additional ingredients on the boiling point are not taken into account. This could result in a runny or weak gel.

It is important to control the boiling time, not just the temperature of the boiling jelly, because chemical reactions occur in the presence of heat and acid that need to be controlled to maintain gel quality. Glycosidic links are hydrolyzed in the presence of heat and acid. Therefore, depolymerization of pectin will occur if the boiling time is too long. This will result in loss of gelling power and the gel may not set.

During the boiling process, sucrose is converted to invert sugar, and the presence of invert sugar in the jelly prevents crystallization of sucrose on storage over a long period. A short boiling time may not allow formation of sufficient invert sugar to inhibit sucrose crystallization over time, especially if the jelly is stored at refrigeration temperatures.

IF THE BOILING TIME IS

- too long—depolymerization of pectin occurs and the gel may not set
- too short—insufficient invert sugar may be formed and crystallization of sucrose may occur

It has been mentioned already that a commercial pectin should be used in addition to the fruit, because the quality of pectin in the fruit varies. An overripe fruit is deficient in pectin, because demethylation and depolymerization occur as the fruit ages. Hydrolysis of only a few glycosidic bonds causes a marked drop in viscosity and gelling power and will produce a weak gel.

GUMS

Gums are a group of complex hydrophilic carbohydrates containing thousands of monosaccharide units. Galactose is the most common monosaccharide found in gums; glucose is usually absent. Gums are often referred to as ***hydrocolloids***, because of their affinity for water and their size; when added to water, they form stable aqueous colloidal dispersions or sols. The molecules are highly branched and as a result most gums are unable to form gels. However, they are able to trap or bind large amounts of water within their branches. Aqueous dispersions therefore tend to be very viscous, because it is difficult for the molecules to move around freely without becoming entangled with each other.

Main Characteristics of Gums

- Larger highly branched hydrophilic polymers
- Rich in galactose
- Hydrocolloids
- Form viscous solutions
- Most do not gel

Gums are classified as soluble fiber because they undergo little digestion and absorption in the body. Therefore, they supply relatively few calories to the diet, as compared with digestible carbohydrates such as starch.

Gums are common in a wide range of food products, including salad dressings, sauces, soups, yogurt, canned evaporated milk, ice cream and other dairy products, baked goods, meat products, and fried foods. They are used as thickening agents in food products, replacing starch. They also are used to assist in the stabilization of emulsions and to maintain the smooth texture of ice cream and other frozen desserts. They are common in reduced fat products, because they are able to increase viscosity and help to replace the texture and mouthfeel that was contributed by the fat.

Gums are obtained from plants and can be separated into five categories: seed gums, plant exudates, microbial exudates, seaweed extracts, and synthetic gums derived from cellulose.

Seed Gums

The seed gums include guar and locust bean gums. These gums are branched polymers containing only mannose and galactose. Guar gum contains a mannose/galactose ratio of 2:1, whereas the ratio is 4:1 in locust bean gum. Guar gum is soluble in cold water, whereas locust bean gum must be dispersed in hot water. Neither gum forms a gel when used alone. However, they may be used synergistically with other gums to form gels.

Guar gum forms gels with carrageenan and guar gum. It is used to stabilize ice cream and it also is found in sauces, soups, and salad dressings.

The presence of guar gum in the intestine seems to retard the digestion and absorption of carbohydrates and slow absorption of glucose into the bloodstream. Use of guar gum in foods therefore may be useful in treating mild cases of diabetes (4).

Locust bean gum typically is used as a stabilizer in dairy and processed meat products. It also may be used synergistically with xanthan gum to form gels.

Plant Exudates

The plant exudates include gum arabic, which comes from the acacia tree, and gum tragacanth. These are complex, highly branched polysaccharides. Gum arabic is highly soluble in cold water and is used to stabilize emulsions and to control crystal size in ices and glazes. Gum tragacanth forms very viscous sols, and is used to impart a creamy texture to food products. It also is used to suspend particles and acts as a stabilizer in products such as salad dressings, ice cream, and confections.

CATEGORIES OF GUMS

- **Seed gums:** guar gum, locust bean gum
- **Plant exudates:** gum arabic, gum tragacanth
- **Microbial exudates:** xanthan, gellan, dextran
- **Seaweed polysaccharides:** alginates, carrageenan, agar
- **Synthetic gums:** microcrystalline cellulose, carboxymethyl cellulose, methyl cellulose

Microbial Exudates

Xanthan gum, gellan gum, dextran, and curdlan are all gums produced using fermentation by microorganisms. Of these, *xanthan* is the most common. Xanthan forms viscous sols that are stable over a wide range of pH and temperature. It does not form a gel, except when used in combination with locust bean gum. It is used in a wide range of products as a thickener and stabilizer and suspending agent. Most salad dressings contain xanthan gum.

Seaweed Polysaccharides

The ***seaweed polysaccharides*** include the agars, alginates, and carrageenans. Unlike most other gums, they are able to form gels under certain conditions.

Carrageenan is obtained from red seaweeds, especially from Irish moss. It occurs as three main fractions, known as kappa, iota, and lambda carrageenan. Each is a galactose polymer containing varying amounts of negatively charged sulfate esters. Kappa carrageenan contains the smallest number of sulfate esters, and therefore is the least negatively charged. It is able to form strong gels with potassium ions. Lambda carrageenan contains the largest number of sulfate groups and is too highly charged to form a gel. Iota carrageenan forms gels with calcium ions.

The carrageenan fractions generally are used in combination. Several different formulations are available, containing different amounts of the individual fractions, and food processors are able to choose formulations that best fit their needs.

The carrageenans are used to stabilize milk products such as ice cream, processed cheese, canned evaporated milk, and chocolate milk, because of their ability to interact with proteins. The carrageenans also may be used with other gums, because of their ability to cross-link with them.

Agar also is obtained from red seaweeds. It is noted for its strong, transparent, heat-reversible gels; that is, agar gels melt on heating and reform when cooled again. Agar contains two fractions—agarose and agaropectin—both of which are polymers of β-D- and α-L-galactose. Agaropectin also contains sulfate esters.

The **alginates** are obtained from brown seaweeds. They contain mainly D-mannuronic acid and L-guluronic acid and they form gels in the presence of calcium ions. Calcium alginate gels do not melt below the boiling point of water; thus, they can be used to make specialized food products. Fruit purees can be mixed with sodium alginate and then treated with a calcium-containing solution to make reconstituted fruit. For example, if large drops of cherry/alginate puree are added to a calcium solution, convincing synthetic cherries are formed. Reconstituted apple and apricot pieces for pie fillings also can be made by rapidly mixing the sodium alginate/fruit puree with a calcium solution and molding the gel into suitable shapes.

FUNCTIONAL ROLES OF GUMS

Gums my be used to perform one or more of the roles in food peoducts.

- **Thickeners**: salad dressings, sauces, soups, beverages
- **Stabilizers**: ice creams, icings, emulsified products
- **Control crystal size**: candies
- **Suspending agents**: salad dressings
- **Gelling agents**: fruit pieces, cheese analogs
- **Coating agents**: batters for deep-fried foods
- **Fat replacers**: low-fat salad dressings, ice creams, desserts
- **Starch replacers**: baked goods, soups, sauces
- **Bulking agents**: low fat foods
- **Source of fiber**: beverages, soups, baked goods

Synthetic Gums

Cellulose is an essential component of all plant cell walls. It is insoluble in water and cannot be digested by man, so it is not a source of energy for the body. It is classified as insoluble fiber.

The polymer contains at least 3000 glucose molecules joined by β-1, 4-glycosidic linkages. Long cellulose chains may be held together in bundles forming fibers, as in the stringy parts of celery.

Synthetic derivatives of cellulose are used in foods as *nonmetabolizable* bulking agents, binders, and thickeners. *Microcrystalline cellulose*, known commercially as Avicel (FMC Corp.), is used as a bulking agent in low-calorie foods. It is produced by hydrolysis of cellulose with acid. ***Carboxymethyl cellulose*** (CMC) and *methyl cellulose* (MC) are alkali-modified forms of cellulose. The former is the most common and it often is called simply *cellulose gum*. It functions mainly to increase the viscosity of foods. It is used as a binder and thickener in pie fillings and puddings; it also retards ice crystal growth in ice cream and the growth of sugar crystals in confections and syrups. In dietetic foods, it can be used to provide the bulk, body, and mouthfeel that normally would be supplied by sucrose. *Methyl cellulose* forms gels when cold dispersions are heated. It is used to coat foods prior to deep fat frying, in order to limit absorption of fat. Two other forms of modified cellulose include *hydroxypropyl cellulose* and *hydroxypropylmethyl cellulose*. These also are used as batters for coating fried foods.

CONCLUSION

Pectins and seaweed polysaccharides are useful for various food products because of their gelling ability. In general, gums are important because they form very viscous solutions, but most do not gel. All these carbohydrates are important to the food industry because of their functional properties and their ability to produce foods with special textures. Used in a wide range of food products as gelling agents, thickeners, and stabilizers, their availability has increased the choice and quality of many convenience foods. Synthetic derivatives of cellulose are important as nonmetabolizable bulking agents, thickeners, and stabilizers in a wide range of calorie-reduced foods.

GLOSSARY

Carboxyl group: COOH group; weak acid group that is partially ionized in solution.

Carboxymethyl cellulose (CMC): Synthetic derivative of cellulose used as a bulking agent in foods. Also known as cellulose gum.

Cellulose: Glucose polymer joined by β-1, 4-glycosidic linkages; cannot be digested by humans and so provides dietary fiber.

Cross-planar bond: Formed when the hydroxyl groups on the carbon atoms involved in the formation of a glycosidic bond are oriented on opposite faces of the sugar rings. Cross-planar bonds occur in pectin and cellulose. They are not digested in the human digestive system.

Gel: Two-phase system with a solid continuous phase and a liquid dispersed phase.

Gums: Complex, hydrophilic carbohydrates that are highly branched and form very viscous solutions; most gums do not gel.

High-methoxyl pectin: Pectin with 50–58% of the carboxyl groups esterified with methanol.

Hydrocolloid: Large molecule with a high affinity for water that forms a stable aqueous colloidal dispersion or sol. Starches, pectins, and gums are all hydrocolloids.

Junction zone: Specific region where two molecules such as pectin align and interact, probably by hydrogen bonds; important in gel formation.

Low-methoxyl pectin: Pectin with 20–40% of the carboxyl groups esterified with methanol.

Pectic acid: Shorter-chain derivative of pectinic acid found in overripe fruits; demethylated; incapable of forming a gel.

Pectic substances: Include protopectin, pectinic acids, and pectic acids.

Pectin: High-molecular-weight pectinic acid; methylated α-D-galacturonic acid polymer.

Pectinic acid: Methylated α-D-galacturonic acid polymer; includes pectins; can form a gel.

Protopectin: Insoluble material found in immature fruits; high-molecular-weight methylated galacturonic acid polymer; cannot form a gel.

Seaweed polysaccharides: Complex polysaccharides that are capable of forming gels; examples include alginates, carrageenan, and agar; used as thickeners and stabilizers in food.

Sol or dispersion: Two-phase system with a solid dispersed phase and a liquid continuous phase.

Steric fit: Ability of molecules to come close enough to each other in space to interact (or fit together).

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CHAPTER 6

Grains: Cereal, Flour, Rice, and Pasta

INTRODUCTION

Throughout the world, there is a great variety of types and amounts of grain products that are consumed by individuals. The World Health Organization (WHO) and many countries including the United States, stress the *nutritional* importance of grains as a foundation of a good diet.

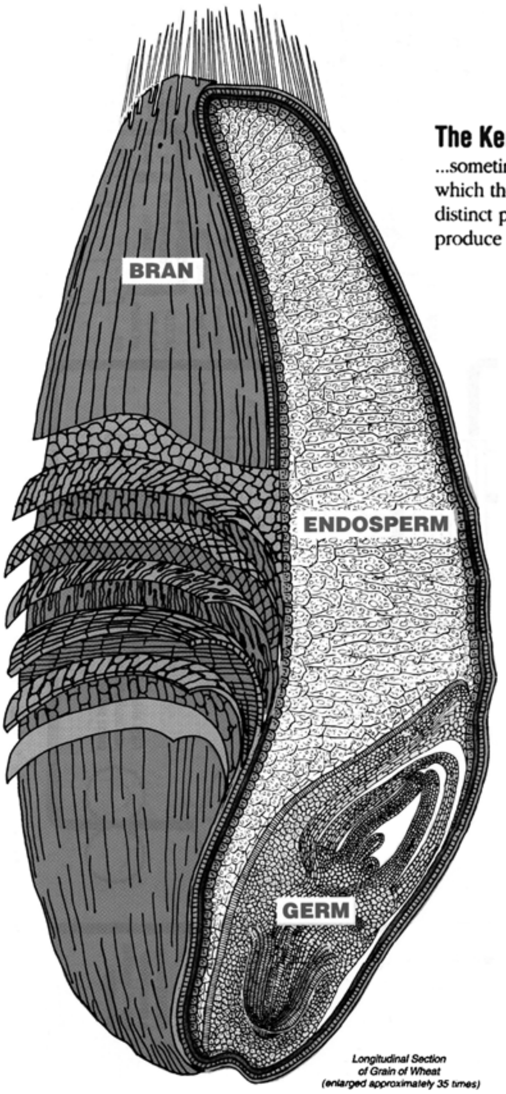
From a *culinary* point of view, consumers see a great variety of grains included in menu offerings: from soups and salads to desserts. Grain consumption has risen substantially in popularity, due in part to a committed number of Americans making more nutritious food selections (1, 2).

In this chapter the physical and chemical properties of grains are addressed. The variety of cereals, milling, type of flours used in bread making and pasta products, safety, and nutritional value are presented. Further discussion of quick breads, yeast breads, the functions of various added ingredients, and details of gluten appear in Batters and Dough, in the chapter on Baked Products (Chapter 15).

STRUCTURE OF CEREAL GRAINS

The structure is similar in all grains. Each kernel of grain is composed of three parts: the *germ, endosperm*, and *bran*, and if *all* are present in a grain, it a "*whole grain*," such as whole wheat. When the bran and/or germ of the seed are removed or separated from the kernel in milling, a product is no longer "whole grain," but rather, "*refined*" (Figure 6.1). Most likely, these two terms are familiar to the reader. It is recommended by the USDA to "make half your grains whole." That advice also appears on many grain-based food products available to the consumer, such as whole grain crackers and cereals. Actual whole grain content is made available on nutrition facts and the ingredients labels.

The ***germ***, or embryo, is the *inner* portion of the kernel, located on the lower end. It composes approximately 2.5% of the seed and is where sprouting begins as



The Kernel of Wheat

...sometimes called the wheat berry, the kernel is the seed from which the wheat plant grows. Each tiny seed contains three distinct parts that are separated during the milling process to produce flour.

Endosperm

...about 83 percent of the kernel weight and the source of white flour. The endosperm contains the greatest share of protein, carbohydrates and iron, as well as the major B-vitamins, such as riboflavin, niacin, and thiamine. It is also a source of soluble fiber.

Bran

...about $14^1/_2$ percent of the kernel weight. Bran is included in whole wheat flour and can also be bought separately. The bran contains a small amount of protein, large quantities of the three major B-vitamins, trace minerals, and dietary fiber — primarily insoluble.

Germ

...about $2^1/_2$ percent of the kernel weight. The germ is the embryo or sprouting section of the seed, often separated from flour in milling because the fat content (10 percent) limits flour's shelf-life. The germ contains minimal quantities of high quality protein and a greater share of B-complex vitamins and trace minerals. Wheat germ can be purchased separately and is part of whole wheat flour.

FIGURE 6.1 Structure of a wheat kernel (*Source*: Wheat Foods Council).

the new plant grows. The germ is the kernel component with the highest percent lipid, containing 6–10% lipid. Rancidity may result from either the lipoxidase *enzyme*, or *nonenzymatic* oxidative rancidity.

Due to this possibility of rancidity, a whole grain product may undergo either germ removal or include antioxidants such as BHA or BHT (See Additives, Chapter 18). The germ contains approximately 8% of the kernel's protein and most of the thiamin.

Another structural part of the kernel is the ***endosperm***. It represents the greatest percentage of the kernel and is primarily starch, held as part of a protein matrix, with an exact composition that differs among grain types and varieties. In wheat, the endosperm is used in making white bread.

Regardless of the grain type, wheat, corn, or another grain, the endosperm is the seed component*lowest* in fat, containing *less* than the *germ*, with up to only 1.5% of the lipid of the seed. It also is *lower* in fiber than the *bran*. It makes up approximately 83% of the seed and has approximately 70–75% of the protein of the kernel.

Varieties of the wheat are carefully specified for use in many food products. Wheat bakes and functions differently depending on the type. For example, wheat may be a *soft* or *hard* type, with the soft wheat variety containing more starch and less protein than hard wheat. The composition makes a difference as shown later.

The *third* major component of a grain is the ***bran***. It is the layered, outer coat of a kernel and consists of an *outside* pericarp layer, offering protection to the seed, and an *inside* layer that includes the seed coat. The bran often is removed by abrasion or polishing in the milling process and may be used in many foods or animal feed. It is approximately 14.5% of the seed, contains 19% of the protein, 3–5% lipid, and minerals such as iron.

Bran provides *cellulose* and*hemicellulose*, both fiber or "roughage" in the diet. Yet, functionally, the bran may differ among grain types and varieties. For example, *wheat bran* includes an insoluble fiber that functions chiefly as a stool softener. *Oat bran* is a soluble fiber that functions among other ways to reduce serum cholesterol.

CULINARY ALERT! A recent conference "Whole Grains Go Mainstream—Breaking Through a Challenging Marketplace" was sponsored in part by the Whole Grains Council. It was an International Conference on Health Benefits, Culinary Choices and Consumer Behavior related to grains.

COMPOSITION OF CEREAL GRAINS

In composition, grains are *structurally* similar as seen; however, they vary in their *nutrient* composition, containing varying amounts of carbohydrate, fat, protein, water, vitamins, and minerals (Tables 6.1 and 6.2). The main nutrient component of cereal grains is carbohydrate, which makes up 79–83% of the dry matter of grain. It exists predominantly as starch, with fiber especially cellulose and hemicellulose, composing approximately 6% of the grain.

Lipid (fats and oil) makes up approximately 1–7% of a kernel, depending on the grain. For example, wheat, rice, corn, rye, and barley contain 1–2% lipid; oats contain 4–7%. The lipid is 72–85% unsaturated fatty acids, primarily, oleic acid, and linoleic acid.

Protein composes 7–14% of the grain, depending on the grain. Cereals are low in the amino acids tryptophan and methionine, and although potential breeding may produce cereals higher in the amino acid *lysine*, it remains the *limiting* amino acid in cereals.

Grain consumption provides half of the protein consumed worldwide. However, in comparison to foods such as milk, meats, or eggs, grains do not include all the essential amino acids contained in animal protein. The protein is of *low biological value*, and therefore, less efficient in supporting body needs.

TABLE 6.1 Typical Percent Composition of Common Cereal Grains (100 g)

Grain	Carbohydrate	Fat	Protein	Fiber	Water
Wheat flour	71.0	2.0	13.3	2.3	12.0
Rice	80.4	0.4	6.7	0.3	12.0
Corn meal	78.4	1.2	7.9	0.6	12.0
Oats, rolled	68.2	7.4	14.2	1.2	8.3
Rye flour	74.8	1.7	11.4	1.0	11.1
Barley	78.9	Trace	10.4	0.4	10.0
Noncereal flours					
Buckwheat flour	72.1	2.5	11.8	1.4	12.1
Soybean flour, defatted	38.1	0.9	47.0	2.3	8.0

Source: Wheat Flour Institute.

Combining food sources of protein is common in cultures throughout the world. The preparation of traditional dishes combines the lower biological value grains with *legumes* or *nuts* and *seeds* to provide the needed amino acids to yield a *complete* dietary protein. For example, a combination of beans with rice, or beans with cornbread, tofu and vegetables, or tofu and cashews, chickpeas and sesame seed paste (tahini) known as hummus, peanut butter on whole wheat bread, and so forth are combinations creating complete proteins. (Botanically, each of these grains, legumes, nuts, and seeds are *fruits* of a plant.)

CULINARY ALERT! All “flour” used in a recipe is not created equal. High-protein “hard” flour absorbs more water than low- protein “soft” flour. The recipe must specify flour type and users must plan accordingly to ensure product success.

Two important proteins present in some grains such as wheat, oat, rye, barley, and triticale are *gliadin and glutenin*. To the extent that these two proteins are present, flour has ***gluten-forming potential***. Then, with sufficient hydration and manipulation of flours containing these proteins, a gummy, elastic ***gluten***

TABLE 6.2 Vitamin, Mineral, and Fiber Content of Wheat Flours (100 g)

Flour	Thiamin B_1 (mg)	Riboflavin B_2 (mg)	Niacin B_3 (mg)	Iron (mg)	Fiber (g)
Whole wheat flour (whole grain)	0.66	0.14	5.2	4.3	2.8
Enriched flour (enriched)	0.67	0.43	5.9	3.6	0.3
White flour (refined)	0.07	0.06	1.0	0.9	0.3

Source: Wheat Flour Institute.

structure (Chapter 15) is created. For example, *wheat* contributes strength and extensibility to the dough, which is desirable in yeast bread making. Other flours without these two proteins cannot rise sufficiently, even with the use of yeast because there are no gluten strands to trap air and gasses.

CULINARY ALERT! Knowing that gluten may be an allergen, some individuals must follow a gluten-free diet.

Another protein, the enzyme α-amylase, is naturally present in grains and promotes dextrinization of starch molecules to shorter-chain polymers and the sugars maltose and glucose. The action of this α-amylase may thin starch mixtures or be detrimental to the bread-making industry, yet it often is added in the form of malt so that there is sugar to feed yeast.

In this section on proteins, we have seen that worldwide grain consumption and grain used in combinations are common. For some nations, just *having* grains is an important issue. For other more affluent and mobile nations, a baker may be concerned about the *baking* properties of the grain. For example, wheat flours *high* in protein absorb a lot of water, while *low*-protein flours do not absorb much. This can mean a dry or a soupy mixture, respectively, and unsatisfactory foods. An experienced baker knows that recipes that work for them in one region of the country may not work in another, and all "flour" is not created equal!

Vitamins present in cereals are predominantly the B vitamins—thiamin (B_1), riboflavin (B_2), and niacin (B_3). These vitamins may be lost in the milling process and so are added back through the process of ***enrichment***. Today, there is less prevalence of the once deadly diseases beriberi and pellagra, due to cereal enrichment with thiamin and niacin, respectively (Table 6.2). Whole grain products contain some fat-soluble vitamins in the germ.

Water is present in cereal grains at levels of 10–14% of the grain. Of course soaking and cooking add water to cereal grains, and the grain size expands as additional water is absorbed. If a flour is *high* in protein content, it absorbs *a lot* of water compared to *low*-protein flour.

Minerals are *naturally* present at higher levels in *whole* grains than in *refined* grains. ***Fortification*** of refined flour with added iron (Table 6.2) is common. Zinc, calcium, as well as vitamins also may be added at *levels beyond/not present in the original grain.*

Fiber content is determined by different analysis and includes *crude fiber* (CF) and *total dietary fiber* (TDF). These two measurements are *not* correlated. CF is composed of *cellulose* and the noncarbohydrate *lignin*. TDF includes cellulose and lignin, plus hemicellulose, pectic substances, gums, and mucilages. Both provide "roughage".

CEREALS

Cereal is a cultivated *grass*, such as wheat, corn, rice, and oats, which produces an edible *seed* (grain or fruit). By definition, ***cereal*** comprises all the cereal products prepared from grain. Then, depending on the composition, cereal crops may be processed into various items such as the following:

- **bread**, using flour or meal from various grains (Chapter 15)
- **cereal**, ready-to-eat or cooked breakfast cereal varieties, such as oatmeal
- **oil**, from germ processing (Chapter 12)
- **pasta**, a dried paste of various flours (and perhaps legumes, herbs, and spices)
- **starch**, from the starchy component of endosperm (Chapter 4)

When stored properly, grains are extremely resistant to deterioration during storage, especially when compared to the perishable dairy, eggs, meats, or fruit and vegetable crops. Grains are utilized extensively in developing and *less* affluent countries where animal products are either not available or not used. In *more* affluent countries, many varieties of grains and whole grains, processed ready-to-eat (RTE) breakfast cereals, and cereal bars and so forth are consumed.

COMMON CEREAL GRAINS AND THEIR USES

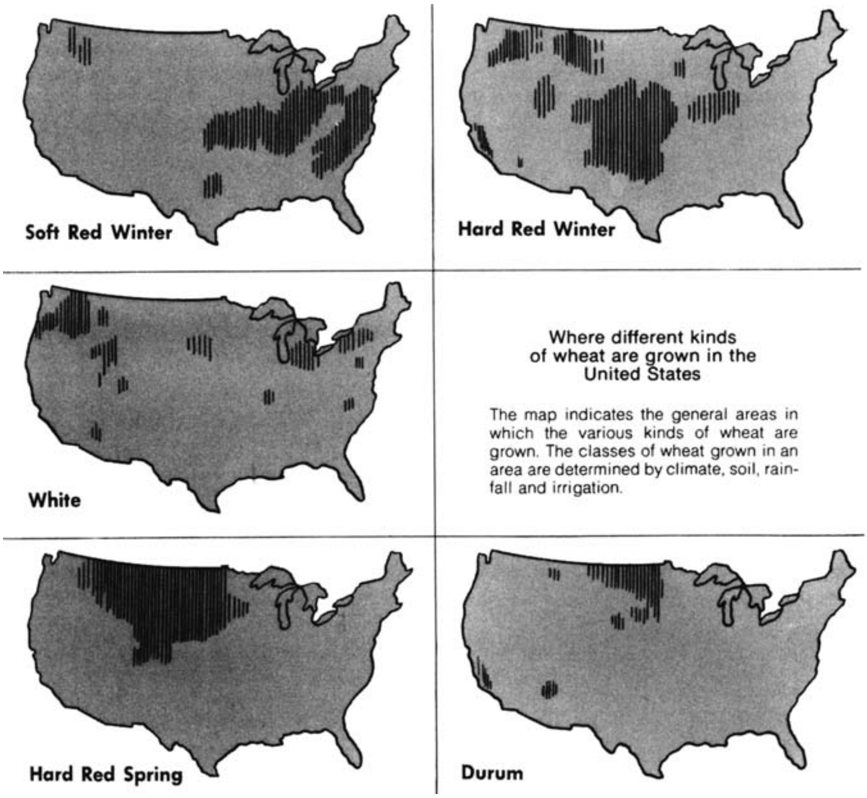
Common cereal grains are noted below. While there is a great variety of cereal grains and their uses throughout the world, the most important and the largest cereal grain consumed by humans in the United States diet is *wheat*. Some wheat also is used for animal feed.

Wheat

Wheat has widespread uses. It may be cracked (bulgur, couscous), made into flour, breads, cereals, and pasta, and is the basis of numerous products that are recognized in diets throughout the world (more later). Some individuals exhibit an intolerance of wheat and its protein (see Gluten Intolerance). Figures 6.2 and 6.3 show where varieties of wheat are grown.

The wheat kernel (wheat berry) is the most common cereal milled into flour in the United States. There are over 30,000 varieties of wheat grown in the United States, grouped into the following *major* classifications: hard red winter, hard red spring, soft red winter, hard white wheat, soft white wheat, and durum wheat. Thus, wheat is named according to several factors: *season grown, texture, and color*.

- Season: Wheat is classified as winter or spring wheat. *Winter wheat* is planted in cold seasons such as Fall and Winter and is harvested in June or July. *Spring wheat* is the spring planting and is harvested in late summer or fall seasons.
- Texture: Wheat is classified as either *hard* or *soft*. Hard wheat kernels contain strong protein–starch bonds, the kernel is tightly packed, and there are minimal air spaces. *Hard* wheat flour forms elastic dough due to its *high* gluten-forming protein content and is the best flour to use for bread making. Hard spring wheat is 12–18% protein and hard winter wheat is 10–15%



Where different kinds of wheat are grown in the United States

The map indicates the general areas in which the various kinds of wheat are grown. The classes of wheat grown in an area are determined by climate, soil, rainfall and irrigation.

FIGURE 6.2 Map showing wheat growth in the United States (*Source:* Wheat Flour Institute).

Each dot represents 1,000,000 bushels

FIGURE 6.3 Map showing where wheat is grown around the world (*Source:* Wheat Flour Institute).

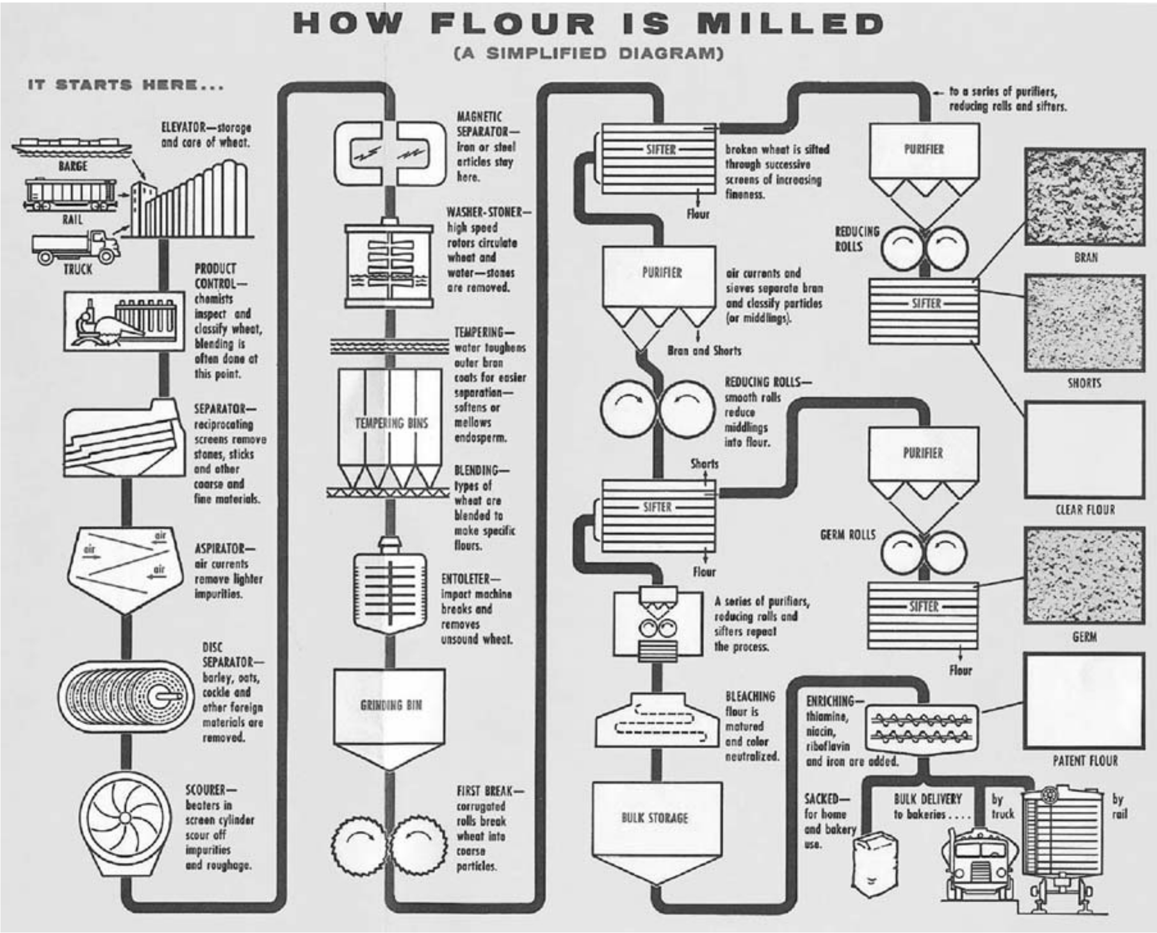


FIGURE 6.4 The milling process
(*Source:* Wheat Flour Institute).

protein. Conversely, *soft* wheat is *lower* in protein, ie, 8–11%, and is desirable for cakes and pastries.

Starch–protein bonds in the kernel break more easily in soft wheat than hard. (Yet inherent differences in the starch or protein components of hard and soft wheat alone do *not* sufficiently explain the differences in hardness.) Hard and soft wheat may be blended to create all-purpose flour that contains about 10.5% protein. In the absence of pastry flour, "instant" (see below) flour and all-purpose flour may be combined.

- Color: *Red, white, and amber*. The color depends on the presence of pigment, such as carotenoid. Durum wheat, for example, is hard wheat and highly pigmented. Its endosperm is milled into ***semolina*** for pasta and couscous. (Yes, most spaghetti is from wheat!)

Milling Process of Wheat. Specific milling tolerances of the ground wheat kernel or "berry" must meet the Food and Drug Administration (FDA) grades to call the product "flour." When milled, each 100 pounds of wheat yields approximately 72 pounds of white flour and 28 pounds of other product, including animal feed.

The conventional milling process (Figure 6.4) of wheat first involves washing to remove foreign substances such as dirt or rocks. Conditioning or tempering by adjustment to water level (the addition or removal of water) follows in order to obtain the appropriate water content and to facilitate the easy separation of the kernel components. Next, wheat is subject to coarse breaking of the kernels into *middlings*. The breaking process separates most of the kernels' outside (bran) and inside core (germ) from the endosperm. Once the endosperm is separated, it subsequently is ground multiple times in reduction rolls to become finer and finer for flour. As the bran and germ are removed, the refined flour contains streams that contain less vitamins and minerals.

If flour streams of the endosperm are blended during the milling process, various flours are created. *Straight grade* flour is a combination of *all* of the mill streams. Typically, home and bakery operations use ***patent flours*** that are 85% straight grade flour and the combination of various highly refined mill streams.

Patent flour is the highest grade of flour; hence, the highest in value. *Short-patent* flour, such as cake flour, contains *more starch* in the starch–protein matrix and is produced by combining fewer streams than the *higher-protein*, *long-patent* flour. The remainder of flour, not incorporated into patent flours, is *clear* flour. It is used when color is not of importance, as it is slightly gray.

It is important to note that flours from the *same* mill *vary* in composition from one year to the next. Also, the *various* flour production mills may produce slightly *different* flours, depending on such factors as geographic location of the crop, rainfall, soil, and temperature. It follows that this variance of crop year, mill, geographic location, and so forth may produce different baking results. Therefore, food manufacturers (and their research and development laboratory) constantly test flour so that variance is minimal or nonexistent. Otherwise flour may produce slightly different products. Of course, using *different flours* may produce *disastrous* results!

Milling also produces the less common instant-blending, instantized, or "agglomerated" flour (3). Instant-blending flour is all-purpose flour that has been hydrated and dried, forming large "agglomerated" or clustered particles, larger than the FDA approves for commercial white wheat flour. It has a more uniform particle size range than white wheat flour and does *not* readily pack down. Instant-blending flour is easily dispersible in water and is used when dispersibility of flour in liquid is preferred or required. It *mixes* into a formulation or recipe *better than* ordinary flour and is free-flowing, pouring like salt or sugar.

CULINARY ALERT! When a product formulation specifies particular flour type and it is unavailable, the baker may combine various blends of flour to yield the correct flour and better results.

Milling of Various Textures of Wheat Produces Some of the Following Flours:

Hard wheat: 12–18% protein

- ***Bread flour*** typically is made of hard red spring wheat kernels, with a *high* protein-to-starch ratio, and is capable of holding a lot of water (2 cups flour holds 1 cup water). It has a high gluten- forming potential forming a very strong and elastic structure, which can hold the air and gasses of yeast. It is not finely milled.

Recall that hard spring wheat has a greater protein content than hard winter wheat. ("Gluten flour," milled from spring wheat, may contain 40–45% protein.)

Hard and soft wheat blend: 10.5% protein

- ***All-purpose flour*** combines the desirable qualities of both hard and soft wheat flour. It does not contain bran or germ and is known as white wheat flour, or simply "flour." It forms a less strong and elastic dough than bread flour and it may be enriched or bleached.

Soft wheat: 7–9% protein

- **Cake flour** contains less protein and more starch than all-purpose flour and holds less water (2–3/4 cup holds 1 cup water). It is *low* in gluten-forming potential, is highly bleached, and finely milled (7/8 cup all-purpose flour + 2 tablespoons cornstarch = 1 cup cake flour).
- **Pastry flour** maintains intermediate characteristics of all-purpose and cake flour. It contains less starch than cake flour and less protein than all-purpose flour.

CULINARY ALERT! Gluten-forming flour is high protein. Yeast is a good leaven to slowly fill the gluten structure as it readily stretches. Non-gluten-forming flour contains less protein, therefore baking powder and baking soda that bubble up immediately are good leavens.

Other flour treatments include the following:

- **Self-rising flour (phosphated flour)** contains 1–1/2 teaspoons of baking powder and ½ teaspoon of salt per cup of flour and provides convenience.
- ***Bleached flour*** is created when the yellowish (mainly xanthophyll) pigment is bleached by oxygen to a white color. Bleaching is achieved (1) naturally by

exposure to oxygen in the air (2 or 3 months), or (2) by the chemical addition of either chlorine dioxide gas or benzoyl peroxide, *bleaching agents* that later evaporate. (Yes, even unbleached flour is bleached, naturally!) Bleaching results in finer grain and a higher volume

- ***Matured flour*** also comes (1) naturally with age or (2) by the addition of *maturing agents*. If matured, gluten elasticity and baking properties of dough are improved because the unwanted effects of excess sulfhydryl groups are controlled. There is less polymerization of gluten protein molecules, and therefore, a less gummy dough (see Chapter 20). Not all bleaching agents are maturing agents, yet chlorine dioxide (above) serves as both types of agent.
- ***Organic (chemical-free) flour*** uses grains that are grown without the application of synthetic herbicides and pesticides.

Wheat foods include bulgur (Figure 6.5), cracked wheat, farina, and couscous as discussed below. *Bulgur* is the whole kernel, ie, parboiled, dried, and treated to remove a small percentage of the bran. It then is cracked and used as breakfast cereal or pilaf. Bulgur is similar in taste to wild rice.

Cracked wheat is similar to bulgur: the whole kernel broken into small pieces, yet not subject to parboiling. Whole grains should be stored in an airtight container in a cool, dark place. *Farina* is the pulverized wheat middlings of endosperm used predominantly as a cooked cereal. It is similar in appearance to grits (corn).

Couscous is a processed form of semolina wheat (Figure 6.6). It is popular throughout the world, especially in Northern Africa and Latin America. It often is served as a pilaf or as tabouli.

In addition to wheat, other common grains are highlighted.

FIGURE 6.5 Bulgur wheat (*Source:* Wheat Foods Council).

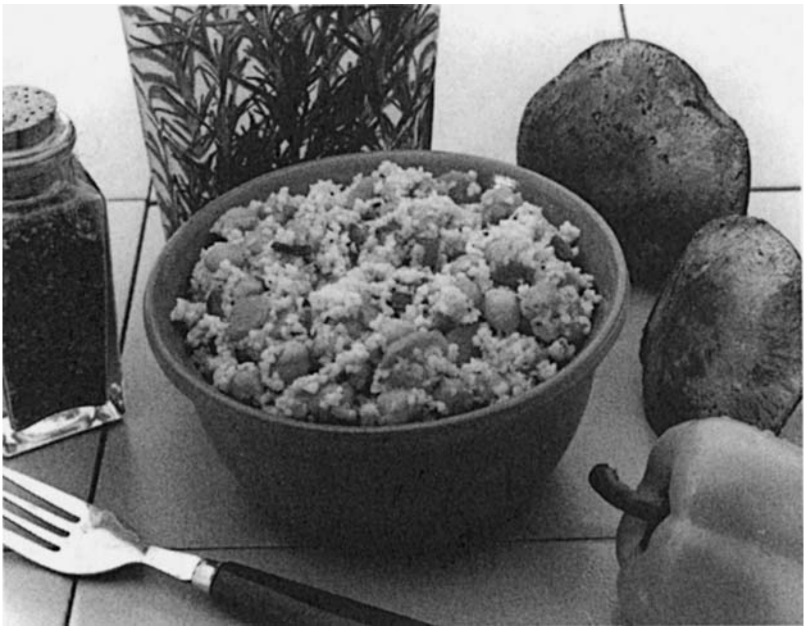


FIGURE 6.6 Couscous (*Source:* Wheat Foods Council).

Rice

Rice is a major cereal grain whose varieties are used as *staple foods* by people throughout the world. Thus, it may be the *major* aspect of a diet or incorporated to a *lesser degree* into the main dish, side dish, or dessert. It commonly is used in the preparation of ready-to-eat breakfast cereals. Rice and rice flour are especially important to persons with wheat allergies, and rice commonly is eaten as a "first food" by infants, as it is food that offers the least cereal allergy.

Rice may be eaten as the *whole grain* or *polished*, shedding the bran. Brown rice contains the bran. Generally, rice is polished during milling in order to remove the brown hull; however, it *al*so removes some of the protein, vitamins, and minerals. When left unpolished, whole rice is *more* subject to rancidity and favor deterioration, as well as insect infestation than polished white rice. Today, most white rice is enriched with vitamins and minerals to add back nutrients lost in milling. [Recall, the once-prevalent deadly disease beriberi resulted from eating polished rice as a staple food (thiamin removed in the milling process).]

Enrichment (Table 6.3) of rice is common and may be achieved by two primary methods. *One method* is to coat the grain with a powder of thiamin and niacin, waterproof it, dry it, and then coat the grain with iron before it is dried again. *Another method* of enrichment involves parboiling or "converting" rice. This allows water-soluble bran and germ nutrients to travel to the endosperm by boiling or a pressure steam treatment. As a result nutrients are retained when the outside hull is removed. Following the steaming process, rice subsequently is dried and polished. Optional enrichment may include riboflavin, vitamin D, and calcium.

Table 6.3 Primary Nutrients for the Enrichment of Rice

Nutrient	mg/lb
Thiamin	2–4
Riboflavin	1.2–2.4
Niacin	16–32
Vitamin D	250–1000
Iron	13–26
Calcium	500–1000

Rice is grown in a variety of sizes. *Long* grain rice (with 3 times the length as width) is *high in amylose* content. *Medium* and *short* grain contain *less* amylose. Rice remains *soft* in hot form; however, leftover rice is hard because the high amylose crystallizes or hardens as it cools. It is recommended that rice puddings prepared with leftover rice use medium or short grain varieties. The same medium or short grain rice is recommended for use in menu items such as sushi, where the food *should* "stick" together.

Amylose Content of Rice

Size variety	% Amylose	
Short grain	15–20%	(less amylose, more sticky)
Medium grain	18–26%	
Long grain	23–26%	(high amylose, less sticky)

CULINARY ALERT! Short grain rice is *low* in amylose. It is sticky and holds ingredients together. Therefore it follows that in a product such as sushi, short grain varieties of rice are preferable over long grain rice.

Rice may be modified to allow flavor and aroma variety, very detectable by some palates. "Rice" may even be made from *pasta* such as when macaroni is shaped to resemble rice in products such as RiceARoni®. It may be processed into flours, starches, cereals, cooking wine, or the Japanese wine, sake. Rice flour is made successfully into items such as low-fat tortillas (4) or noodles. Wild "rice" actually is *not* rice, but is derived from seeds of another reedlike water plant.

New rice development shows that rice is used to create many new food and beverage products. For example, rice-based ingredients are used to reduce the oil content absorbed in the frying process. Genetically modified rice strains have been developed to be high in beta-carotene, have cancer-fighting properties, or be healthy beverage bases.

Numerous research studies have focused on shelf-stable cooked rice, ready-to-eat cereal, confectionery applications, rice oils, and flavored rice. Defatted rice bran extracts, aromatic rice, pregelatinized rice flours, starches, and rice syrups are chosen as food ingredients, depending on the application (5).

While persons in Asia may eat as much as 300 pounds of rice per person, per year, Americans eat less than that but have shown a doubling of rice intake, to eat more than 21 pounds per year (5). Rice use in a wide variety of foods continues to be common.

Corn

The majority of corn is used for animal feed, although corn is a staple cereal food of many people and nations. It is lacking in the two essential amino acids, tryptophan and lysine, but research continues to explore the addition of a protein trait to corn DNA

Sweet corn is actually a cereal; however, it is commonly eaten as a vegetable. *Field corn* has nonvegetable uses, including starch that is of value to growers and consumers alike. The whole kernels of special breeds of corn containing 11–16% moisture are desirable for popcorn where the kernel increases in volume as the water escapes as steam.

- The *whole or partial kernels* may be coarsely ground (perhaps stone-ground) and used to create cornmeal or masa. Cornmeal is popular in cornbread and tamales, corn tortillas, snack foods, and items such as taco shells (Figure 6.7).

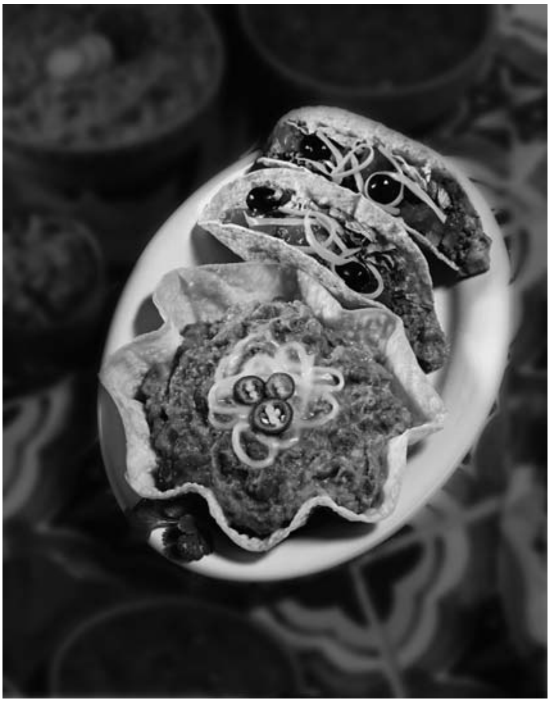


FIGURE 6.7 Corn taco shells (*Courtesy of SYSCO® Incorporated*).

It may be soaked in alkali such as lime (calcium hydroxide) for 20–30 minutes for a better amino acid balance and greater protein availability. This soaking process may sacrifice some niacin (vitamin B_3), but it adds calcium.

- The *endosperm* of corn may be made into hominy, ground into grits, or used in ready-to-eat breakfast cereals or cornstarch. It may be hydrolyzed in hydrochloric acid or treated with enzymes to produce corn syrup or high-fructose corn syrup (HFCS) (Chapter 14).
- The *germ* yields corn oil.

CULINARY ALERT! For use in bread making, corn needs to be combined with other flour, such as wheat flour, since corn by itself yields a dense bread and does not contain the proteins gliadin and glutenin that form extensible gluten structures.

OTHER GRAINS

Other less commonly consumed grains are discussed in the following text. For some readers, the following grains may be very familiar and frequently utilized. For others, these same grains are *not* used at all and may be unheard of! Grains other than the wheat, rice, and corn previously discussed are *not* abundantly consumed, but they offer great variety (Figure 6.8) and often grow in more adverse environmental conditions where the more common grains will not grow. The seeds are used both as forage crops and as food cereals in different parts of the world.

FIGURE 6.8 Breads may be prepared using a variety of grains (*Source:* Wheat Foods Council).

Barley

Barley is "winter-hardy" and is able to survive in the frost of cold climates. It is used for human and animal consumption. Barley is served as a cooked cereal, or the hull of the kernel is removed by abrasion to create pearled barley, ie, commonly used in soups. Additionally, although barley may not be eaten as a whole grain, it is incorporated into many foods including breads, pilafs, or stuffing, or it may be used for ***malt*** production. Barley is the most common malt as it has sufficient enzyme content to hydrolyze the starch efficiently to sugar.

Malt:

- In order to create malt, the barley grain is first soaked in water. This soaking causes the germ to sprout and produces an enzyme that hydrolyzes *starch* to a shorter carbon chain, maltose *sugar*. Maltose is a fermentable carbohydrate which is then used to feed yeast and produce CO_2 and ethyl alcohol. (The alcohol and CO_2 are important for brewing alcoholic beverages and for baking.) Dried malt is used in a variety of products including brewed beverages, baked products, breakfast cereal, candies, or malted milks.
- Consumers following a gluten-free diet (no wheat, oats, rye, or barley) must avoid malt. They should read ingredients labels to determine (1) *if* malt is an ingredient in the food, and (2) the *source* of the malt.

Millet

Millet is the general name for *small* seed grass crops. The crops are harvested for food or animal feed (fodder). It is a major crop in some countries and is used as cereal or to make breads or soups. It includes proso (the most common), finger, foxtail, and pearl millet. Minor millets include barnyard, browntop, guinea, kodo, and little varieties of millet. Some millet is utilized in birdfeed, for cattle, hogs, poultry, and sheep.

Millet is related to sorghum. *Sorghum* is a special type of millet with *large* seeds, typically used for animal feed, but it is the primary food grain in many parts of the world, where it is ground and made into porridge and cakes. It also is used to yield oil, sugars, and alcoholic beverages. A common variety of sorghum grown in the United States is milo; there also are waxy varieties. Overall, sorghums are resistant to heat and drought, and therefore are of special value in arid and hot regions of the world. Sorghum is a gluten-free way to produce malt.

A *very tiny* millet grain that has been used for centuries in the Ethiopian diet is *teff* or t'ef (*Eragrotis tef,* signifying "love" and "grass"). The seeds are approximately 1/32 of an inch in diameter, with 150 weighing as much as a kernel of wheat! Considering its size, it has a small endosperm in proportion to bran, and therefore is primarily bran and germ. It is ground for use in flatbread. Commercial production of teff has been started in the United States (6). It is cultivated in states including Idaho and South Dakota.

Oats

Oat is an important cereal crop fed to animals such as horses and sheep and also used by humans. It is valued for its high protein content. In milling, the hull is removed and oats are steamed and "rolled" or flattened for use in food. Oats are incorporated into many ready-to-eat breakfast cereals and snack foods. Oat bran is a soluble fiber that has been shown to be effective in reducing serum cholesterol.

Due to the fact that oats have a fairly high fat content, as far as grains go, rancidity may rapidly develop. Lipase activity in the grain is destroyed by a few minutes of steam treatment.

Quinoa

Quinoa (keen-wa) is the grain highest in protein, but *not* an abundantly consumed grain. The small, round, light brown kernels most often are used as a cooked cereal (7).

Rye

Rye is richer in lysine than wheat but has a relatively low gluten-forming potential, and therefore, does not contribute as good a structure to dough as does wheat. It frequently is used in combination with wheat flour in breads and quick breads and is made into crackers. There are three types of rye—dark, medium, and light—often baked into bread. Rye may be sprouted, producing malt or malt flour.

Triticale

Triticale is a *wheat* and *rye* hybrid, first produced in the United States in the late 1800s (8). As a crop, it offers the disease resistance of wheat and the hardiness of rye. It has more protein than either grain alone, but the overall crop yield is not high, so its use is not widespread. Triticale was developed to have the baking property of wheat (good gluten- forming potential) and the nutritional quality of rye (high lysine).

In relation to gluten intolerance or celiac disease, many grains are less subject to rigorous testing than wheat, rye, barley, oats, and triticale. Considered to be safe are grasses such as sorghum, millet, and teff.

NONCEREAL "FLOURS"

Although they do *not* have the composition of grains, various *legumes* and *vegetables* may be processed into "flour." For example, soy and garbanzo beans (chick peas) are legumes (from the Leguminosae family) that may be ground into "flour" for addition to baked products. Soy aids in maintaining a soft crumb. Cottonseeds (Malvaceae family), and potatoes (tubers) also may be processed into "flour." Buckwheat (fruit of *Fagopyrum esculentum* crop) contains approximately 60% carbohydrate and may be used in the porridge kasha or animal feed. Cassava (tuber) is the starch-yielding plant that yields tapioca and is a staple crop in parts of the world.

COOKING CEREALS

Cereal products expand during cooking due to retention of the cooking water. *Finely* milled grains such as cornmeal, corn grits, or wheat farina should be *gently* boiled and stirred only *occasionally* in order to prevent mushy and lumpy textures. *Whole or coarsely* milled grains such as barley, bulgur, rice, and oats (and buckwheat) may be added to *boiling* water and stirred occasionally.

To control heat, cereal products may be cooked in the top of a double boiler over boiling water. A disadvantage of this cooking method is that heating time is lengthened compared to direct heating without use of a double boiler.

Pasta is added to boiling water and boiled uncovered until the desired tenderness (typically al dente) is achieved. The addition of a small amount [1/2 teaspoon (2.5 ml) household use] of oil prevents boilover from occurring.

CULINARY ALERT! Excessive stirring of any milled grain (especially finely milled grains) results in rupturing of the grain contents and is unpalatable, as the cereal forms a gummy, sticky consistency.

BREAKFAST CEREALS

Breakfast cereals may be hot or cold. An American religious group not wanting to consume animal products started the production of ready-to-eat breakfast cereals. The Western Health Reform Institute in Battle Creek, Michigan, produced, baked, and then ground a whole meal product to benefit the healthfulness of its patients. A local townsperson, J.H. Kellogg, and his brother W.K. Kellogg started a business with this idea, applying it to breakfast food. A patient, C.W. Post, did the same. (Both names are still popular cereal manufacturers today.)

Breakfast cereals in many forms quickly became popular. Flaking, shredding, puffing, etc, and the production of various forms soon expanded. Although convenient, some criticize the levels of ingredients, including sugar and fiber, in ready-to-eat breakfast cereals. Enrichment and fortification also became a common practice for breakfast cereals, which are some of the most fortified foods available.

PASTA

Pasta is the paste of milled grains (alimentary paste), extruded through a die or put through a roller. The crushed (not finely ground) endosperm of milled durum spring wheat, known as semolina, is used in the preparation of high-quality pasta products. *Lower-quality* pastas that do *not* use semolina also are available to the consumer. They typically taste "starchy" and are pasty in texture. Although taste may not be affected, rinsing cooked pasta products prior to service may result in the loss of nutrient enrichment.

Pasta frequently appears on restaurant menus and home tables in the form of salads, side dishes, and main dishes. If pasta is processed to include legumes as part of the formulation, a *complete protein* may be formed in a single food. For example, pasta may be formulated to include pureed vegetables, herbs, and spices as well as cheeses. Pasta may be cholesterol-free or made of nonwheat flour, such as rice. "Technological breakthroughs now make it possible to enjoy rice pasta that tastes, looks, and cooks like regular pasta" (10). Rice flour also may be used by persons following a gluten–free diet because they cannot have semolina (wheat) pasta.

Figures 6.9 and 6.10 show some of the diversity present in pasta. A variety of products including macaroni, noodles, and spaghetti are created by extrusion. To distinguish, *macaroni* does *not* include eggs in its formulation. *Noodles must* contain not less than 5.5% (by weight) of egg solids or yolk (9).

FIGURE 6.9 Various pasta products
(*Source:* Wheat Foods Council).

FIGURE 6.10 Durum Montage.
(*Source:* Wheat Foods Council).

NUTRITIVE VALUE OF GRAINS

Grains make a significant nutritive contribution to the diet (11). Whole grain products and processed cereal products contribute carbohydrates, vitamins such as B vitamins, minerals such as iron, and fiber to the diet in creative ways. Fortifi-

FIGURE 6.11 Ready-to-eat breakfast cereal
(*Source:* Wheat Foods Council).

cation with vitamin D and calcium are presently under consideration. Ready-to-eat varieties of breakfast cereals frequently are consumed in the more developed countries and many are highly fortified with essential vitamins and minerals, including folate (Figure 6.11).

HABITS OF HIGHLY SUCCESSFUL WHEAT VARIETIES

Almost everyone knows about the two main kinds of wheat—bread wheat and durum wheat - but few are aware that wheat also has three distinct growth habits: spring, winter, and facultative. A variety's growth habit limits its survival to certain geographic areas, mostly defined by latitude, which is why growth habit is fundamental to CIMMYT's classification of wheat growing environments.

Spring-habit wheats have a continuous growth cycle with no inactive period. In areas where winters are severe, such as northern Kazakhstan or Canada, wheat is planted in the spring after there is no risk of frost. In areas with very mild winters, such as India or Australia, spring wheat is sown in the autumn and grows through the winter.

Winter-habit wheats evolved to withstand low winter temperatures, such as those that prevail in North Korea or northwestern Europe. To flower, they require exposure to cold during their early growth. Winter wheats are sown in autumn and start to grow before winter sets in, when they become inactive. The plants resume rapid growth in the spring as temperatures rise.

Facultative-habit wheats tolerate cold more than spring wheats and less than winter wheats, but they do not require extended exposure to cold temperatures to reproduce. These wheats are found in transition zones between true spring and winter wheat regions.

Because these types of wheat have become adapted to contrasting climatic conditions, each has developed resistance or tolerance to stresses common in those conditions. These kinds of wheat probably also have distinct genes for high and stable yield. In some cases, the special genetic advantages of one wheat type can be useful in other wheat types.

For example, some of CIMMYT's highest-yielding wheats have resulted from crosses between spring and winter wheats that exploited the yielding ability and stress resistances/tolerances of both wheat types. "This breeding approach brings genes together in completely novel combinations," says van Ginkel. "The genes were already widely present, but they were in geographically distinct-and often distant-locations."

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[*] Worldwide update: International Maize and Wheat Improvement Center
http://www.cimmyt.org/whatiscimmyt/recent_ar/Amapof.htm#Highly
The abbreviation "CIMMYT" derives from the Spanish version of the name above: Centro Internacional de Mejoramiento de Maíz y Trigo.

Grains are low in fat, high in fiber, and contain no cholesterol, *although* cooked foods, baked breads, cereals, rice, and pasta dishes may be prepared with fats, sugars, eggs, and refined flours, which change the nutritive value profile. Many ready-to-eat breakfast cereals are high in sugar and/or low in fiber. The recommended number of grains is 6 oz per day on a 2000 calorie intake.

CONCLUSION

Cereals are the edible seeds of cultivated grasses and many cereal foods are prepared from grain. A kernel contains bran, endosperm, and germ; however, if "refined," cereals contain *only* endosperm and are no longer whole grain. For example, *wheat flour* is not the same as *whole wheat flour*. Common cereal grains include wheat, rice, and corn, although other grains such as barley, millet, oats, quinoa, rye, and triticale may be used as a component in meals. Dried grains have a very long storage life and much of the world depends on them for food.

Over 30,000 varieties of wheat exist, classified according to season, texture, and color. *Hard* wheat is used for bread making and *soft* wheat for cakes and pastries.

Semolina flour from hard durum wheat is used for pasta production. Pasta is the paste of milled grains, primarily wheat, and increasingly appears in the American diet. It is a complex carbohydrate and low-fat food.

Rice is a staple food of much of the world. It grows as (extra long), long, medium, and short grain rice and grows in a variety of flavors that are used in many entrees, side dishes, even desserts. Corn is also common.

Cereals are included as the base of numerous food guides throughout the world, indicating that they are major foods of a nutritious diet. The USDA recommends that 6 oz should be consumed each day. This recommendation may be met with the great variety of products that are available in the marketplace.

GLOSSARY

All-purpose wheat flour: White flour, not containing the bran or germ. Combining the properties of hard and soft wheat.

Bleached flour: Bleaching the pigment to a whiter color naturally by exposing pigment to air or by chemical agents.

Bran: The layered outer coating of the kernel, offering protection for the seed.

Bread flour: Made from a hard wheat kernel, with a high protein–starch ratio; high gluten potential.

Cereal: Any edible grain that comes from cultivated grasses.

Endosperm: The starch-storing portion of the seed that produces white flour and gluten.

Enrichment: Adding back nutrients lost in milling.

Fortification: Adding nutrients at levels beyond that present in the original grain.

Germ: The embryo; the inner portion of the kernel.

Gluten: Protein substances (gliadins, glutenins) left in the flour after the starch has been removed, which when hydrated and manipulated produce the elastic, cohesive structure of dough.

Malt: Produced from a sprouting barley germ. Long glucose chains are hydrolyzed by an enzyme to maltose, ie, involved in both feeding yeast and producing CO_2. May be dried and added to numerous products.

Matured flour: Wheat flour, ie, aged naturally or by chemical agents to improve gluten elasticity and baking properties of dough.

Organic flour: Flour from crops grown without the use of chemicals such as herbicides and insecticides.

Patent flour: Highest grade of flour from mill streams at the beginning of the reduction rolls. High starch, less protein than mill streams at the end of reduction rolls.

Pasta: The paste of milled grains, usually the semolina from durum wheat, extruded through a die to produce a diversity of shaped products. They are dried and then cooked in large amounts of water. Included are macaroni, noodles, spaghetti, ravioli, and the like.

Semolina: Flour milled from durum wheat.

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GLOSSARY FOR CEREALS, FLOUR, AND FLOUR MIXTURES

Oregon State University

Select additional definitions for a better understanding of cereals, flour and flour mixtures.

Carmelization is the development of brown color and caramel flavor as dry sugar is heated to a high temperature; chemical decomposition occurs in the sugar.

Carotenoid pigment is the yellow-orange compound produced by plan cells and found in various fruit, vegetable, and cereal grain tissues; for example, beta-carotene.

Coagulation is the change in protein after it has been denatured that results in hardening or precipitation and often is accomplished by heating.

Fermentation is the transformation of organic substances into smaller molecules by the action of microorganisms; yeast ferments glucose to yield carbon dioxide and alcohol.

Gliadin is the water-insoluble protein that contributes stickiness and tackiness to gluten structure.

Graham flour is flour essentially from the entire wheat kernel. It may be ground to varing degrees.

Green flour is flour that has not been aged or matured.

Milling is the process that generally involves the separation of the bran and germ from the endosperm which is subsequently subdivided.

Oxidation is a chemical reaction in which oxygen is added or electrons are lost.

Proofing is the last rising of bread dough after it is molded into a loaf and placed in the baking pan.

Rope is a bacterial contamination that can originate in the flour bin or in the various constituents used to make bread. It will make a loaf of bread sticky and "ropy" in the interior.

Staling refers to those changes in quality that occur in baked products after baking. Generally, there is a loss of flavor, softening of the crust or development of a leathery crust, and increased firmness of the crumb.

Starch gelatinization is the swelling of starch granules when heated with water, often resulting in thickening.

Straight grade white flour theoretically should contain all the flour streams resulting from the milling process, but actually 2 to 3% of the poorest streams are withheld.

White wheat flour is a food made by the grinding and sifting of cleaned wheat (definition, FDA).

Z. Holmes, Oregon State University.

CHAPTER 7

Vegetables and Fruits

INTRODUCTION

Vegetables are the edible portion of plants eaten with (or as) the main course. They are in salads and soups. Vegetables may be processed into beverages or vegetable starches, eaten fresh or lightly processed, dried, pickled, or frozen. They impart their own characteristic flavor, color, and texture to diets and undergo changes during storage and cooking. Ranked next to the cereal crops wheat, rice, and corn, potatoes are the most prolific vegetable crop grown for human consumption.

Fruits are defined in several ways. *Botanically*, fruits are the mature ovaries of plants with their seeds. Therefore, this definition includes all grains, legumes, nuts and seeds, and common "vegetable-fruits" such as cucumbers, olives, peppers, and tomatoes. When defined and considered in a *culinary role*, fruit is the fleshy part of a plant, usually eaten alone or served as a dessert. Fruits are high in organic acids and sugar—higher than vegetables.

The nutritive value of vitamins, minerals, fiber, and other compounds contained in fruits and vegetables is extremely important to the diet. Additional dietary and medicinal benefits of fruits and vegetables are being discovered. "Vary your veggies" and "focus on fruits" is the USDA advice in selecting vegetables and fruits as part of a healthy diet. If following a 2000 calorie diet, USDA advice suggests 2-1/2 cups of vegetables plus 2 cups of fruit per day (USDA).

STRUCTURE AND COMPOSITION OF CELL TISSUE

Vegetables and fruits are composed of both *simple* and *complex* cells. The *simple* cells are similar to one another in function and structure and include *dermal* tissue and *parenchyma* tissue. ***Dermal tissue*** is the single-layer *outside* surface of leaves, young stems, roots, and flowers, while ***parenchyma tissue*** makes up the majority of the plant and is where basic molecular activity such as the synthesis and storage of carbohydrate by sunlight (photosynthesis) occurs.

Complex tissue includes the vascular, collenchyma, and sclerenchyma *supporting tissue*. Major vascular tissue consists of the xylem and phloem; xylem conducts water from the roots to the leaves, and phloem conducts nutrients from the leaves to the roots. These tissues may be located in the center of the vegetable, as is seen in carrots, for example.

A plant is made*primarily* of simple *parenchyma* tissue (Figure 7.1). Each cell is bounded by a cell wall produced internally by the protoplast. The wall serves to support and protect cell contents and their retention, influx, or release. When the wall is *firm*, the original shape and texture of the cell are maintained. However, when the wall is *destroyed* (by cutting, dehydration or cooking), it breaks and spills its contents into the surrounding environment. Thus, water, sugars, or water-soluble vitamins of a cell may be lost.

The *primary* cell wall is made of ***cellulose***, hemicellulose, and pectic substances including pectin. Older, more mature plants also may have a *secondary* cell wall composed of *lignin* (see Chemical Composition of Plant Material), in addition to the primary cello wall.

Inside the parenchyma cell wall is the protoplast composed of three parts—*plasma membrane, cytoplasm, and organelles*. The ***plasma membrane*** surrounds the functional cell, while the ***cytoplasm*** of the protoplast includes all of the cell contents inside the membrane yet outside the nucleus. The ***organelles*** include nucleus, mitochondria, ribosomes, and plastids. It is the plastids that contain fat-soluble material such as fat-soluble vitamins and fat-soluble pigments including chlorophyll and carotenoids (discussed in a subsequent section of this chapter.)

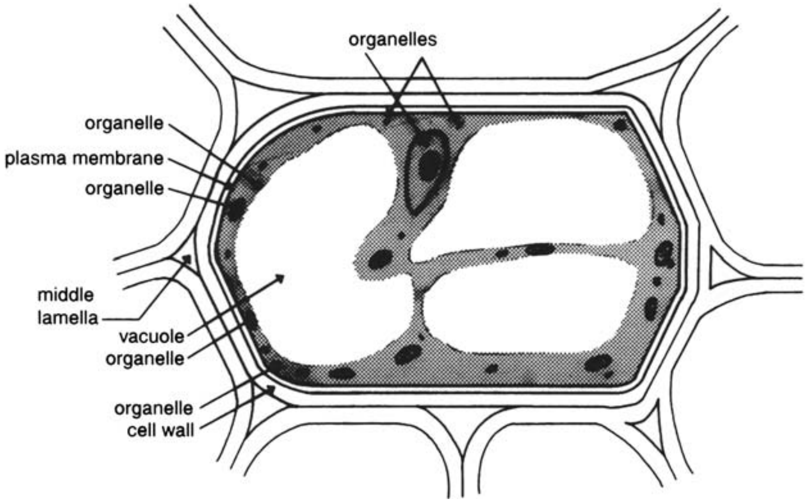


FIGURE 7.1 Components of a parenchyma cell
(source: Division of Nutritional Sciences, New York State College of Human Ecology).

Outside the cell wall, *between* adjacent cells, is the ***middle lamella***. This is the "cementing" material between adjacent cells and it contains pectic substances, magnesium and calcium, water, and air spaces.

Each parenchyma cell contains an inside cavity known as a ***vacuole***. It may be *large* in size, holding plentiful water, and comprising the major portion of parenchyma cells, or it may be *small* in size. In an intact, *uncooked* cell, vacuoles hold sufficient water and provide a desirable *crisp* texture to the cell. The opposite effect is noted in *wilted* or cooked cells.

The ***cell sap*** of the vacuole contains the water-soluble materials including vitamins B and C, sugars, inorganic salts, organic acids, sulfur compounds, and the water-soluble pigments. These cell sap components may escape into the surrounding soaking/rehydrating/cooking water.

CHEMICAL COMPOSITION OF PLANT MATERIAL

Carbohydrate

Carbohydrate constitutes the *largest* percentage of the dry weight of plant material. It is the basic molecule formed during photosynthesis when water (H_2O) and carbon dioxide (CO_2) combine to yield carbohydrate (CHO) and oxygen (O_2). Carbohydrate is present in simple and complex forms. For example, *simple* carbohydrates are the *mono*saccharides, including glucose and fructose; and *di*saccharides such as sucrose, which may increase during the fruit ripening process. *Complex* carbohydrates or *poly*saccharides are synthesized from simple carbohydrates and include cellulose and starch.

Various complex carbohydrates and the effect of heat on those carbohydrates are discussed in the following (see also Chapter 3):

- **Starch** is the storage component of carbohydrate located in roots, tubers, stems, and seeds of plants. When subjected to heat and water, starch absorbs water and gelatinizes (see also Chapter 4). Vegetables vary in their starch content. Some vegetables such as potatoes are starchy, some moderate, and others such as parsley are less starchy. Starch is digestible as the bonds between the glucose units are α–1,4.
- ***Cellulose*** is water-insoluble fiber that provides *structure* to plant cell walls. The molecular bonds between glucose units are β-1,4; therefore, cellulose remains *indigestible* to humans, although it may be softened in cooking.
- ***Hemicellulose*** fiber provides structure in cell walls and the majority is *insoluble*. It is softened when heated in an alkaline environment, such as if baking soda is added to cooking water for the purpose of green color retention.
- ***Pectic substances*** (see also Chapter 5) are the firm, intercellular "cement" between cell walls, the gel-forming polysaccharide of plant tissue, and are hydrolyzed by cooking. Large *insoluble* forms of pectin become *soluble* pectin with ripening of the plant material.

In addition to carbohydrates, there is a noncarbohydrate fiber material present in the complex vascular and supporting tissue. It is ***lignin*** and is found in older vegetables. Lignin remains unchanged by heat and may exhibit an unacceptable "woody" texture.

Protein

Overall, less than 1% of the composition of a*fruit* is protein, and protein *is low* in most *vegetables*. Protein is most prevalent in legumes—peas and beans—but even then it is an *incomplete* protein as it lacks the essential amino acid, methionine.

Protein, present as enzymes, may be extracted from plants and used in other foods. Examples include the proteolytic enzymes that contribute the beneficial tenderizing effects to meats such as *papain* (derived from papaya),*ficin* (obtained from figs), and *bromelain* (extracted from pineapple).

Fat

Fat composes approximately 5% of the dry weight of roots, stems, and leaves of vegetables. It makes up less than 1% of the dry weight of a fruit, except for fruits such as avocados and olives, which contain 16% and 14% fat, respectively. Fat is instrumental in development during the early growth of a plant.

Vitamins

The vitamins present in vegetables and fruit primarily are *carotene* (a vitamin A precursor) and *vitamin C*. *Betacarotene*, a precursor of vitamin A, is present in dark orange fruits and vegetables and as an underlying pigment in green vegetables. Vitamin B_1 (thiamin) also is present. Fruits supply more than 90% of the water-soluble vitamin C and a major percentage of the fat-soluble vitamin A in a diet.

Water-soluble vitamin losses may occur upon soaking when vitamins leach out and also in heating. Losses are primarily in heating. Nutritive quality also may deteriorate due to enzymatic action. Specifically, the enzymes ascorbic acid oxidase and thiaminase can cause nutritional changes in vitamins C and B_1, respectively, during storage. Therefore, retention of these vitamins is controlled by deactivating the enzymes in blanching prior to freezing (1).

CULINARY ALERT! It is interesting to note that vitamins A and C, so plentiful in fruits and vegetables, are both listed on nutrient facts labels as vitamins that Americans lack. Therefore, increase consumption of fruits and vegetables.

Minerals

Fruits and vegetables, especially the latter, contribute minerals to the diet, notably calcium, magnesium, and iron. (The USDA mypyramid suggests consuming a greater amount of vegetables compared to fruit each day.) Calcium ions may be *added* to canned vegetables to promote firmness and lessen softening of pectic substances. Since the oxalic acid in spinach and the phytates in peas *bind calcium*, decreasing its bioavailability, calcium is *not* added to these vegetables.

Water

Water is found *in* and *between* plant cell walls. Some of its functions in the plant are to transport nutrients, to promote chemical reactions, and to provide plants with a crisp texture if cell membranes are intact.

Water constitutes a small percentage (10%) of seeds and is a substantially larger percent of leaves. It makes up 80–90% of a plant, as is evidenced by the drastic size reduction of a measure of vegetables that is subject to dehydration.

CULINARY ALERT! Think about how the volume of plant material changes significantly when a food dehydrator is used to remove water from food.

Phytochemicals (more in Appendices)

Phytochemicals are plant chemicals. They are nonnutrient materials that may be especially significant in disease prevention and controlling cancer. These chemicals are the focus of much research concerning their importance to human health.

The list is long of the many examples of such plant chemicals. It includes the beta-carotene of carotenoid pigments, the flavonoid group of pigments, as well as the sulfur-containing allyl sulfide and sulforaphane. Additionally, dithiolthiones, indoles, and isothiocyanates in cruciferous ("cross-shaped blossom," cabbage family) vegetables, isoflavones, phytosterols, protease inhibitors, saponins in legumes, and limonene and the phenols of citrus fruit are among the plant chemicals that may be effective in disease prevention.

TURGOR PRESSURE

As previously mentioned, the structure of plant material to a large degree is dependent on the water content of the parenchyma cell. A raw product still attached to the plant prior to harvesting generally is crisp because the vegetable or fruit contains a large percentage of water, which provides turgidity to the plant. A plant's ***turgor pressure*** is the pressure that water-filled vacuoles exert on the cytoplasm and the partially elastic cell wall.

Soon after the fruit or vegetable is "picked" from the plant, water is lost to the air (evaporation) due to air flow with its evaporation or due to low humidity storage. As a result, there is a loss of turgor pressure. The product becomes limp, wilted, and dehydrated. If the parenchyma cell is still *intact* (*not cooked* or otherwise destroyed), turgor of this wilted, limp product may be restored.

CULINARY ALERT! It is possible to rehydrate or recrisp by storage in high humidity (refrigerator's hydrator box or crisper) or by minimal soaking in warm, 70–90°F (21–32°C), water.

After soaking, plant pores then reclose and hold the absorbed water if it is refrigerated for 6 hours (2). Soaking raw plant material may be discouraged though, as water-soluble nutrients and pigments may escape by purely physical means, into the soaked water. [To rehydrate lettuce, it is suggested that it should not be soaked, but rather placed in only 2 inches or so of warm water (2). Sprays of dips to make the produce waterproof also may be employed.

Once the parenchyma cell is subjected to cooking, *osmosis* ceases and *diffusion* occurs, which changes the texture, flavor, and shape of fruits. ***Osmosis*** represents water movement across a *semipermeable* membrane. ***Diffusion*** signifies water *and solute* movement across a *permeable* membrane.

PIGMENTS AND EFFECTS OF ADDITIONAL SUBSTANCES

Plant pigments enhance the aesthetic value of fruits and vegetables for humans, as well as attract insects and birds, which fosters pollination. These pigments are subject to change with ripening and processing of the raw vegetables or fruits. The four pigments found in plants are *chlorophyll*, the green pigment; *carotenoids*, a yellow, red, or orange pigment; and the flavonoids, both *anthocyanin*, the red, blue, or purple pigment, and *anthoxanthin*, the white pigment.

High-performance liquid chromatography (HPLC) generally is used for plant pigment analysis (3). A discussion of the major pigments and a description of how they may change appears in the following material.

Chlorophyll

Perhaps the most well-recognized plant pigment is ***chlorophyll***, the green pigment found in the cell chloroplast, since it is responsible for photosynthesis (ie, converting sunlight to chemical energy). It is *fat-soluble* and may appear in vegetable cooking water if it also contains fat.

Chlorophyll structurally is a porphyrin ring containing magnesium at the center of a ring of four pyrrole groups (Figure 7.2). Phytol alcohol is esterified to one of the pyrrole groups, and it confers solubility to fat and fat solvents. Methyl alcohol is attached to another pyrrole group.

If the magnesium in chlorophyll is *displaced* from its central position on the porphyrin ring, an *irreversible* pigment change occurs. A number of factors including prolonged storage, the heat of *cooking*, changes in *hydrogen ion* concentration (pH), and the presence of the minerals, zinc and copper, produce a drab, olive-green colored pigment. In a raw form the membrane does not allow H to contact/change a pigment.

Initially, as green vegetables are *heated*, air is removed from in and between the cell and a *bright green* color becomes apparent. Then internal organic acids

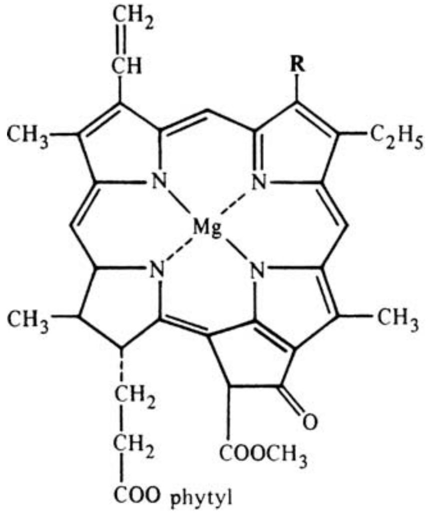


FIGURE 7.2 Chlorophyll.

are released and hydrogen displaces magnesium, producing pheophytins. Either magnesium-free *pheophytin a*, which is a gray-green pigment, or *pheophytin b*, an olive-green pigment, is formed. These changes to the chlorophyll pigment become more marked with time, so a short cooking time is recommended.

As well, cooking the product *uncovered* for the first 3 minutes allows the escape of volatile plant acids that would otherwise remain in the cooking water and react to displace magnesium. Using a cover, less change of chlorophyll occurs. (This is not true of all vegetable pigments as seen later.)

When heated, green-pigmented vegetables *high* in acid content undergo *more* color change than vegetables *low* in acid and less than fruit with its *high* acid. Green vegetables such as *raw* broccoli change color to the underlying yellowish color as the chlorophyll degrades.

CULINARY ALERT! Pigments may change from the natural color due to extended heating and release of the plant's *internal* organic acids; therefore, minimum cooking is preferred. In addition to the internal organic acids, an *external* acid environment (ie, acid added to cooking water) causes the natural green color to change into olive-green pheophytin.

As opposed to an acid environment, an *alkaline* environment also affects the green pigment. The alkaline sodium bicarbonate (baking soda) produces and maintains a desirable green color. The soda reacts with chlorophyll, displacing the phytyl and methyl groups on the molecule, and the green pigment forms a bright-green, water-soluble chlorophyllin. However, although producing a desirable *appearance*, that benefit is accompanied by an unacceptable *loss of texture*, due to softening of hemicellulose. Sodium bicarbonate also *destroys ascorbic acid (vitamin C)* and*thiamin (vitamin B1)*. Therefore, the addition of alkali is *not* recommended.

CULINARY ALERT! Sodium bicarbonate (baking soda) has a positive effect on color; however, negatively it affects texture and nutritive value.

The minerals copper and zinc may be contained in cutting or chopping knives or copper bowls or colanders, producing *undesirable* color changes in chlorophyll by displacing magnesium.

Regardless of the manner in which chlorophyll is changed, when the chlorophyll is destroyed, a second underlying carotenoid pigment may become apparent. This is discussed below.

Carotenoids

The ***carotenoids*** are red, orange, and yellow *fat-soluble* pigments in fruits and vegetables, including *carotenes* (the hydrocarbon classification) and *xanthophylls* (the oxygenated class). They are found in chloroplasts along with chlorophyll, where the green pigment dominates, and also in chromoplasts without chlorophyll. The carotenoid pigment is seen especially in flowers, fruits, including tomatoes, peppers, and citrus fruits, and roots, including carrots and sweet potatoes.

Carotenes are unsaturated hydrocarbons containing many carbon atoms. The conjugated double bonds (ie, double bonds alternating with single bonds) are responsible for the color; the greater the number of conjugated double bonds, the deeper the color. For example,

- *Beta*-carotene is naturally orange in color and contains a six-membered ring at each end of the chain (Figure 7.3).
  In comparison to beta-carotene:

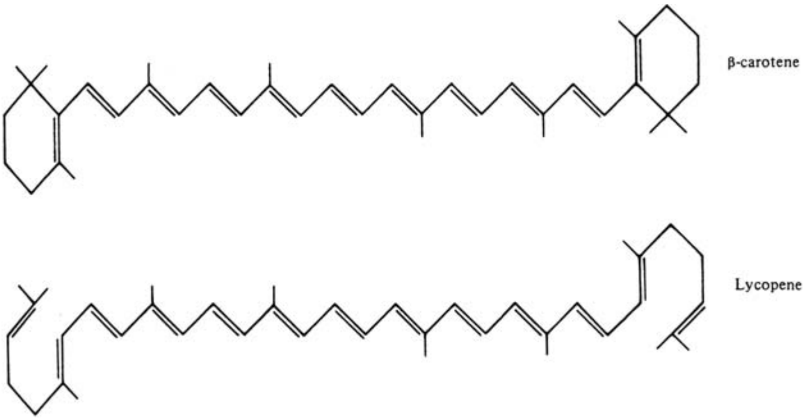


FIGURE 7.3 Beta-carotene, lycopene.

- *Alpha*-carotene has one *less* conjugated double bond and is *paler* in color.
- *Lycopene*, found in tomatoes and watermelon, has the *deepest red-orange color* because it has two *more* double bonds than beta-carotene and it has two open rings (Figure 7.3) at each end of the chain.

There are hundreds of types of carotenes. The most well-known carotene is the aforementioned beta-carotene, cleaved by an enzyme in the intestinal mucosa to yield vitamin A. In all, 40 or more carotenoids are known to be precursors of vitamin A (3).

Xanthophylls are the yellow-orange colored derivatives of carotenes containing carbon, hydrogen, and oxygen. Autumn leaves show evidence of destruction of the green chlorophyll pigment, as the carotenes, and “autumn xanthophylls” that existed along with the chlorophyll become visible (3). Corn contains the xanthophyll *cryptoxanthin* and green leaves contain*lutein*. Paprika also contains xanthophyll pigment.

The carotenoid pigment may undergo autoxidation due to the large number of double bonds. This oxidation may result in “off-flavor” and color loss, yielding unsatisfactory products. Antioxidants such as butylated hydroxy anisole (BHA), butylated hydroxy toluene (BHT), or tertiary butylated hydroxy quinone (TBHQ) are frequently added to a wide variety of foods containing fruits and vegetables, herbs, or spices to prevent this detrimental oxidation [See food additives (Chapter 18)].

While *oxidation* causes development of a *lighter-color* cooked vegetable, *caramelization* of plant sugar may result in a *darker-color* cooked vegetable. It is recommended that carotene-pigmented vegetables should be either covered during cooking or cooked quickly, as in stir-frying. Since the pigment is fat soluble, table fat such as butter or margarine should be minimized or omitted in cooking as the pigment may become paler.

Cooking time does *not* negatively affect carotenoid pigments as much as it does for chlorophyll and changes are *not* as noticeable. However, upon *heating* and in the presence of *acid* some molecular isomerization occurs. Specifically, in carotenoids, the predominant *trans* molecular form, naturally present in plants, is changed to*cis* configuration in a matter of a few minutes and the pigment becomes less bright. Alkali environments do *not* produce a color change.

Carotenes provide color in food. Food technologists have developed annatto, carrot, paprika, and tomato *extracts* to provide color in foods. (Pinkish-white flowers of the annatto plant with their small reddish-orange seeds inside offer dye used to color foods such as cheddar cheese.)

In addition to extracts mentioned above, herbs and spices also provide carotene coloring and flavor. Albeit in *small* amounts in foods, they contribute to vitamin A values that appear on nutrition labels and their use is expected to grow (4). They supply advantageous nutrients such as beta-carotene. This addition offers the same nutrients as a diet of yellow, green, and leafy vegetables, although in significantly lesser amounts.

Carotene from vegetables or fruits may prevent oxidation of body tissues and development of *cancer*, although much remains unknown about possible benefits of *supplements* of this biologically active component of plant material. The American Dietetic Association advocates *foods* in the diet as the best source of good nutrition (see Nutritive Value of Vegetables and Fruit) rather than supplements.

CULINARY ALERT! Cooking change is minimal for carotenoids.

Another group of pigmented compounds consisting of anthocyanins and anthoanthins are the flavonoids.

Anthocyanin

Anthocyanin (Figure 7.4) is the red, blue-red, blue, or purple pigment in fruits and vegetables such as blueberries, cherries, raspberries, red cabbage, red plums, and rhubarb (not beets; see Betalaines). The *skins* of radishes, red apples, red potatoes, grapes, and eggplant also contain anthocyanin pigment. It is prevalent in buds and young shoots and is an underlying pigment of chlorophyll, which becomes apparent as a purplish pigment in autumn leaves when chlorophyll decomposes.

Anthocyanins contain a *positively charged oxygen* in the central group of the molecule and belong to the flavonoid group of chemicals. Thus they are distinguished from the orange-red found in carotenoids. These pigments are *water-soluble* and are found in the cell sap of plants. They may be released into the cooking water with soaking or prolonged heat exposure.

In the following is a discussion regarding anthocyanin and pH.

- **pH and Color**. Care must be taken when working with the anthocyanin pigments. Mixed fruit juices for a punch drink or fruits incorporated into baked goods with alkaline leavens may produce undesirable color. Either the addition of *alkali* or in an alkaline cooking medium produces unwelcome violet-blue or turquoise color.

  In an *acidic* environment, the anthocyanin pigment exhibits a more characteristic red color. A tart, acidic apple often is added to red cabbage while cooking in order to produce a more appealing finished product.
- **pH and Texture**. Textural characteristics *also* are affected by pH. If acids such as lemon juice or vinegar are added to fruits and vegetables (anthocyanin

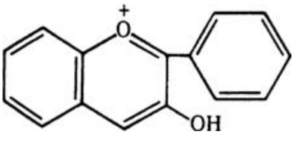


FIGURE 7.4 Anthocyanin.

pigment) for better color, it should be *after* desired softening has occurred because acid prevents softening (see Cooking Effect).

Recall the *negative* changes to the chlorophyll pigments when it is cooked *covered* and retaining plant acids. The opposite is true of anthocyanins. Cooking the anthocyanin pigmented vegetable *with* a cover is recommended for better color because *plant acids* are then *retained* in the cooking water. If fruits containing anthocyanins are added to batters and doughs, such as in the preparation of blueberry muffins,*acidic* buttermilk also is incorporated to assist in preserving color. Color changes that occur in cooking are reversible.

Metals, such as iron from non-stainless-steel preparation tools, also change pigments. Metals can change the natural purplish pigment to a blue-green color. Therefore, food products containing the anthocyanin pigment often are canned in lacquer-coated (enamel-lined) metal cans to prevent the product acid from interacting with the can metal and causing undesirable color changes.

CULINARY ALERT! Anthocyanin color is subject to reversible changes in cooking.

Anthoxanthin

A fourth major pigment, ***anthoxanthin*** pigment (Figure 7.5) also is a flavonoid and is similar to anthocyanin, but it exists in a *less* oxidized state, as the oxygen on the central group is *uncharged.* (Recall: anthocyanins contain a *positively charged oxygen.*) This classification represents flavone, flavonol, flavanone, and flavanol pigments and includes fruits such as apples, or vegetables such as cauliflower, onions, and potatoes. Anthoxanthins are white, or pale yellowish, *water-soluble* pigments found in a plant's cell sap.

Short cooking is desired. With *prolonged* heat, the pigment turns into a brownish gray color. For example, white, anthoxanthin potatoes, with their low organic acid content, may become dark colored after prolonged cooking due to formation of an iron–chlorogenic acid complex. Some anthoxanthins may *change* to anthocyanins and exhibit a pinkish tinge if vegetables are overcooked.

In *acid* environments, anthoxanthin becomes lighter. (Therefore, in household use, cooking in one teaspoon of cream of tartar per quart of water may be useful in lightening the color.) If cooking water is *alkaline* or contains traces of iron salts,

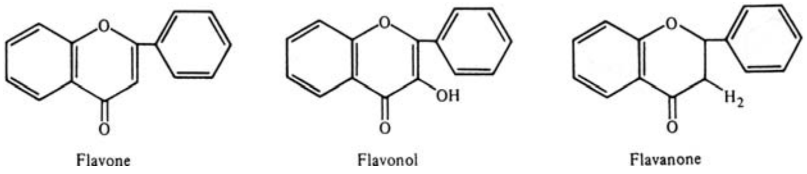


FIGURE 7.5 Anthoxanthin.

the result may be a *yellow* or *brown* discoloration of white cooked vegetables. Cooking in aluminum cookware also causes the same discoloration.

CULINARY ALERT! Short cooking of the anthoxanthin pigment is advised. It remains whiter in acid.

Betalaines

Betalaines are a minor group of pigments that contain a nitrogen group in the molecular structure. They are similar to but *not* categorized as anthocyanins or anthoxanthins. These pigments differ in color. For example,

- Betacyanines are **red-colored** like anthocyanins at a pH of 4–7.
- Betaxanthines are **yellow-colored** like anthoxanthins at a pH above 10.
- Betalaine below a pH of 4 is **violet-colored**.

A lacquered can (as with anthocyanins) is used in order to prevent color changes that may result from metals in the can reacting with the betalaine pigment.

Tannins

Tannins (tannic acid) are polyphenolic compounds that add both color and astringent flavor to foods. They may be responsible for the *unwanted* brown discoloration of fruits and vegetables, as well as for the *desirable* changes that provide tea leaves with their characteristic color. They range in color from pale-yellow to light brown, and due to their acidic nature they tend to cause the mouth to pucker. (Astringents shrink mucous membranes, extract water, and dry up secretions.)

The term represents a broad group of compounds found in plants—normally in bark, fruit, leaves, and roots. Tannins, such as the brownish pigment found in tea leaves, may be used as the brown colored dye in dyeing fabrics or tanning leather. Food tannins found in wines and teas contain antioxidant properties correlated with good health. Tannins precipitate proteins causing them to become a solid and "settle" out of a solute phase (however, proteins will *float* if they are less dense than the solvent).

FLAVOR COMPOUNDS

The flavor of cooked vegetables is greatly influenced by the presence sulfur of both *allium* and*brassica* compounds, although aldehydes, ketones, organic compounds, and alcohols are contributors to flavor. Some of the favorable sulfur compounds, including allyl sulfides, may increase excretion of carcinogens from the body, according to the American Cancer Society (ACS).

Allium

Vegetables that are of the genus ***allium*** include chives, garlic, leeks, onions, and shallots, each different members of the *lily* family. Onions, for example, contain strong sulfur compounds and exhibit enzyme activity when cut, causing the eyes to tear (lachrymatory effect). Similarly, garlic undergoes an enzymatic change to sulfur compounds, precursor *(+)-S-allyl-*L*-cysteine sulfoxide*, producing the identifiable garlic odor.

Since these flavor compounds in plants are *water soluble*, they may be lost from the vegetable to the water, then volatized as steam during cooking. It follows then, that if a *mild* flavor is desired in cooked onions, a *large* amount of boiling water and cooking *uncovered* for a long time period is recommended. In that manner, sulfur flavor compounds are degraded and vaporized. Inversely, a *sweeter*, *more concentrated* flavor is produced if *less* water and a *cover* is used. The most *intense* flavor results from cooking in fat where flavor is simply *not* lost.

CULINARY ALERT! Allium: Mild if the vegetable is cooked in a large amount of water, uncovered. A concentrated, stronger flavor is apparent if less water and covered cooking are chosen. Intensity is greatest when cooking in oil.

Brassica

Vegetables of the genus ***Brassica*** include broccoli, brussels sprouts, cabbage, cauliflower, kale, kohlrabi, mustard greens, rutabaga, and turnips. They are of the*mustard* family and are known as *cruciferous* vegetables which have a cross-shaped blossom on the young, growing plant. As opposed to allium, the *naturally mild* flavor of the *raw* vegetables with brassica *becomes quite strong* and objectionable with prolonged *cooking* as hydrogen sulfide is produced.

Hence, for optimal flavor of *brassica* flavored vegetables, a *small* amount of briskly boiling cooking water and *short* cooking is advised. Also, in order to allow the volatile organic acids to escape, it is recommended that the vegetables should be *uncovered* at the beginning of the cooking process. Then they may be *covered* to keep the cooking time short.

Some vegetables of the Brassica genus, such as cabbage, contain a sulfur compound known as *sinigrin*. Sinigrin may interact with an enzyme, myrosinase, released from the cut or bruised cell and produce potent mustard oil. *The* (+)-*S-methyl-*L*-cysteine sulfoxide* compound may convert to the more desirable dimethyl disulfide.

CULINARY ALERT! Brassica: A small amount of water, and cooking for a short time, with a cover, prevents development of an unacceptable strong-flavor.

Organic Acids

The tart, sour taste of fruits may be attributed to organic acids, such as citric acid, malic acid, or tartaric acid. Vegetables contain a greater variety of organic acids, yet maintain a less acidic pH level than fruits.

Concentrates, Extracts, Oils, Spices, and Herbs

Flavor may be derived from concentrates, extracts, oils, herbs, and spices that are incorporated into food as it is processed. They are used as an alternative to fresh, frozen, or dehydrated vegetables in a product formulation and they provide products with a pure, consistent quality of flavor when they are added. *Concentrates* impart the vegetable's characteristic flavor. *Natural plant extracts* may be used to yield the flavors and aroma of fresh herbs and spices. *Essential oils* also are removed from a plant and concentrated to produce flavoring oils. The replacement ratio for some herbs and spices may be 1:10 (5).

Although there may not be a clear-cut distinction between a herb and spice, a herb is generally from the herbaceous part of plants. According to the American Spice Trade Association (ASTA), a spice is "any dried plant product used primarily for seasoning purposes." Spices may come from fruits, flowers, roots, or seeds, as well as from shrubs and vines. They enhance color, flavor, and palatability and they exhibit antimicrobial properties (6). (The FDA does not include dehydrated vegetables in its definition of spices, but rather they are "flavors.")

A tremendous amount of folklore goes along with herbs and spices, which may be used for medicinal as well as culinary purposes. While *traditional medicine* has been in practice for centuries, which includes the use of herbs and spices, such traditional medicine may be combined in practice *today* with *Western or modern medicine*. In fact, the National Center for Complementary and Alternative Medicine, established by the National Institutes of Health, has as its mission to seek out effective and alternative medical treatment, to evaluate the outcomes, and report findings to the public.

VEGETABLE CLASSIFICATIONS

Vegetable classifications demonstrate the parts of the plant eaten as food. This varies throughout the world. The eight common parts, beginning with underground parts of the plant and progressing to those parts growing above ground, are as follows:

- **Roots**—underground; beet, carrot, jicama, parsnips, radish, rutabaga, sweet potato, turnip, yam. ("Sweet potatoes" are a yellow to orange color flesh, either dry or moist. In the US, they may be known as "yams," and both names are stated on a label. The nonorange, true "yam" is yellow, white, or purple-pigmented flesh root vegetables.)

- **Tubers**—underground; enlarged fleshy stem; starch storage area after leaves manufacture carbohydrates; buds or eyes form new plants; Irish potato, Jerusalem artichoke.
- **Bulbs**—stems with an underground bulb of food reserve; garlic bulb, leeks, onions, shallots, spring onions (green onions or scallions do not possess a real bulb).
- **Stems**—a plant's vascular system, nutrient pathway; a lot of cellulose; asparagus, celery, kohlrabi, rhubarb.
- **Leaves**—the manufacturing organ for carbohydrate which is then stored elsewhere in the plant; brussels sprouts, cabbage, lettuce, parsley, spinach; also seaweed and "greens" such as beet, collards, kale, and mustard greens.
- **Flowers**—clusters on the stem; artichoke, broccoli, cauliflower.
- **Fruits**—the mature ovaries with seeds, generally sweet, and fleshy; apple, banana, berry, and orange; but including vegetable–fruits such as avocado, cucumber, eggplant, okra, olive, pepper, pumpkin, snap beans, squashes, and tomato that are not sweet, but contain seeds.
- **Seeds**—in fruit of a plant; may be in pods; includes legumes such as dried beans, and peas, and peanuts, and in the United States sweet corn (although it is a grain, not vegetable); may be sprouted.

HARVESTING AND POSTHARVEST CHANGES

Schedules and procedures for harvesting (as well as processing) produce should be strictly followed to ensure fruits and vegetables with the highest quality. Crops are harvested at *different* stages of maturity prior to storage and they are likely to be larger and less tender with age. It may be ideal to harvest *less mature* fruits and vegetables or to allow them to "ripen on the vine."

Another ideal practice is that of *cooling* fresh produce *in the field* and then canning *close* to the field prior to transport. This practice minimizes negative changes in quality.

After harvest, fruits and vegetables continue to undergo respiration, the metabolic process of taking in oxygen (O_2) and giving off carbon dioxide (CO_2), moisture, and heat. The maximum rate of respiration occurs just before full ripening. *Climacteric* fruits, such as the apple, apricot, avocado, banana, peach, pear, plum, and tomato, ripen *after* harvesting. Tropical fruits such as the papaya and mango are also climacteric as is the avocado.

On the other hand, *nonclimacteric fruits*, such as the cherry, citrus fruit, grapes, melon, pineapple, and strawberry, ripen *prior* to harvest.

- Climacteric: ripens AFTER harvesting
- Nonclimacteric: ripens BEFORE harvesting

Natural postharvest sunlight, artificial, or fluorescent light exposure may form a green chlorophyll pigment and *solanine* (bitter, and toxic at high levels) in some vegetables such as onions or potatoes. Green colored spots may appear just below the skin, and if small, these small amounts may be easily cut away.

Proper packaging for shipping is significant (see Chapter 19). Storage conditions that retain this moisture or heat reduce negative changes in the fruit or vegetable, such as mold or rot.

RIPENING

In between the maturity and ripening stages there is a lot of enzymatic activity. Although ripening may be *unseen*, there is internal hormonal and enzyme activity prior to change in the physical appearance. Eventually, evidence of ripening can be *seen* and felt to-the-touch in a physical evaluation. For example, changes from the green color (due to chlorophyll degradation) allow more carotenoid pigment to be visible in the fruit as it ripens. Flavor changes are noted with an *increase* in the sugar and *decrease* in the acid content.

Noticeable ripening changes also occur due to the production of odorless and colorless ethylene gas. For example, the emission of this gas generates a softening of the plant cell wall. *Ethylene gas* is a naturally occurring hydrocarbon produced by some vegetables and fruits, especially apples, bananas, citrus fruit, melon, and tomatoes. In particular, lettuce and leafy vegetables as well as any bruised fruits are especially susceptible to undesirable respiration due to the presence of ethylene gas. Storage conditions should *separate* ethylene producers from other fruits that do not require ripening. (One bad apple spoils the whole bunch!)

In addition to *natural* ethylene gas, there is also *artificially* produced ethylene gas, made by the burning of hydrocarbons. Food distributors may introduce measured doses of ethylene gas into a closed food chamber for the purpose of ripening unripened fruits before they are sold to retailers. The effectiveness of ethylene in achieving faster and more uniform ripening is dependent on the pulp temperature and stage of maturity of the fruit and the relative humidity of the ripening room (7).

CULINARY ALERT! A technique for ripening fruit at home is to place unripened fruit in a closed paper bag in order to trap ethylene gas and speed up desirable ripening.

There is some control for the unwanted effects of natural ethylene gas, which may overripen the fruit and result in poor quality. *Gibberellic acid* may be added to the external storage environment of fruits and vegetables. A preharvest application of this plant growth regulator delays ripening and retains firmness in a fruit, both of which are important considerations in postharvest handling, storage, and transportation.

In the process of *senescence* (overripening) the intracellular protopectin develops into water-soluble pectin. *Overripe* fruits and vegetables become soft or mushy as the once-firm cells separate from one another. To control unwanted ripening and extend shelf life, edible waxes and other treatments, including irradiation treatment, may be applied to fruits and vegetables (Chapter 19). The enzymes sucrose synthetase and pectinase are used in measuring maturity of *some* potatoes and fruits.

Refrigeration may reduce adverse chemical reactions. As well, manipulation of CO_2 and O_2 through controlled atmosphere storage, controlled atmosphere packaging, and modified atmosphere packaging offers control of ripening (Chapter 19).

ENZYMATIC OXIDATIVE BROWNING

When bruised or cut during preparation, discoloration of *some* fruits or vegetables may occur. For example, when some varieties of apples, apricots, bananas, cherries, peaches, pears, eggplant, or potatoes are bruised or cut, the product *enzymes* are exposed to *oxygen* in the atmosphere and the produce is subject to undesirable *browning*. ***Enzymatic oxidative browning*** occurs when the plant's phenolic compounds react with enzymes in the presence of oxygen.

Control measures to prevent enzymatic oxidative browning may not be easy. For example, more than one substrate may exist in a fruit or vegetable, oxygen may come from intercellular spaces, not solely surface air, and the responsible enzyme must be denatured. Damaging enzymes spread in storage, and as mentioned earlier, it is true that "one bad apple spoils the whole bunch!"

One effective control of browning is to avoid contact between the substrate and oxygen. In order to achieve this, food may be covered with a *sugar syrup* to block oxygen, or it may be covered with a film wrap that limits oxygen permeability. *Another* control is the application of a commercially prepared *citric acid powder* or *ascorbic acid* to the cut fruit surface. Lemon juice in a ratio of 3:1 with water may be applied to the surface of the fruit, according to the Produce Marketing Association (2). In this manner, the vitamin C juice is oxidized instead of the pigment and the acidic pH inhibits enzymatic action.

Pineapple juice, because of its sulfhydryl groups (–SH) acts as an antioxidant, and is an*additional*, effective means of protection against browning. [As with lemon juice, the Produce Marketing Association recommends dipping cut fruits in pineapple juice (3:1 ratio, pineapple juice to water) for controlling enzymatic oxidative browning.] Sulfur compounds in the juice interfere with the darkening of various foods, such as cut fruit, cut lettuce leaves, and white wine. However, due to health concerns of a small percentage of the population allergic to sulfites, the use of sulfiting agents to prevent browning is restricted in raw products. Other agents may be used.

Home gardeners usually blanch fruits or vegetables prior to freezing. *Blanching* destroys the polyphenol oxidase enzyme and enables the product to withstand many months of freezer storage *without* degradation. Blanching entails the placement of (usually) cutup fruit or vegetable pieces in boiling water for a precise period of time prior to freezing. The exact length of time depends on the volume and texture of the product.

CULINARY ALERT! Avoid contact between the substrate and oxygen; cover susceptible fruit with a sugar syrup or film wrap. Apply lemon juice, orange juice, pineapple juice, or a commercial treatment to the fruit surface in order to control browning.

COOKING EFFECT

Vegetables and fruits may be consumed raw. Others are made ready for consumption by methods such as baking, boiling, frying, pressure-cooking, sautéing, steaming, stir-frying, and so forth (Figure 7.7). When short cooking periods and cooking methods such as steaming are selected, the effect is minimal loss of both flavor and nutritive value. Also, steaming retains the natural color as it does not allow contact between released internal acids and the food. Cooking introduces appearance and texture changes, as well as flavor and nutritive value changes, as shown in the following.

Water Retention/Turgor

Once cooked, the cell membranes *lose* their selective permeability, and unlike the simple movement of water/osmosis that occurs in *raw* produce the*cooked* cell membranes allow the additional movement of sugars and some nutrients as well as water. *Diffusion* occurs as substances move from an area of higher concentration to an area of lower concentration and the plant cell loses its form, water, and turgor.

Color

The natural color of *raw* fruits and vegetables varies, and the color of *cooked* fruits and vegetables is influenced by a number of factors as previously discussed in this chapter. These factors include the natural plant pigment and pH, age, duration of cooking, use of a pan lid, cooking method employed, and surrounding environment. *Blanching* serves to inactivate enzymes and expel intercellular air that may negatively affects color.

Cooking in aluminum or cast-iron cookware may *negatively discolor* cooked products; therefore, the use of stainless steel is recommended for cooking vegetables or fruits. Another color change accompanies the use of sodium bicarbonate, which yields a *brighter green* color. However, it is not recommended, as vitamin and texture losses occur.

Texture

In addition to color changes, cooking also changes the *texture* of a vegetable. The texture of the cooked vegetable depends on a number of factors. These factors include pH, age, duration of cooking, and water composition. For example, lengthy cooking in boiling *alkaline* water drastically softens texture as hemicelluloses break down, cellulose is softened, and pectins degrade. The addition of *acid*, such as the addition of a tomato to another vegetable recipe, yields a firm cooked vegetable because tissues do not soften and pectin precipitates.

Helping to retain texture are calcium ions. They are *naturally* present in hard water or may be *added* to many canned vegetables in commercial processing. For example, canning tomatoes with the addition of calcium *retains* the texture of cooked plant tissue forming insoluble salts with pectic substances. For a similar reason, brown sugar or molasses are common additives that are useful in retaining texture as well, eg, Boston baked beans. Of course, the texture also is related to maturity of the plant, which may become tougher and "woody" due to the presence of lignin in older plants.

Flavor

The flavor of cooked vegetables is dependent on factors such as the classification as either *Allium* or *Brassica* and loss of both water-soluble organic acids and sugars from the vacuole. Additionally, sugar, fat, herbs, and spices vary the flavor of vegetables and may get a wary person to eat the vegetables!

Nutritive Value

Nutritive value is presented in much more detail *later* in this chapter. Now, discussion is limited to *cooking effect* on nutritive value. The value of cooked fruits and vegetables is influenced by nutrients naturally present in the food, the type of cooking medium, and duration of cooking. Through diffusion, water-soluble vitamins and sugars in the cell sap are lost from parenchyma cells and may be oxidized. Minerals present in plant material are inorganic substances that cannot be destroyed (although they may be discarded in fruit or vegetable trimmings).

Of nutritional benefit in cooking is a*short cooking* time in a *minimal* amount of water or *steaming* the vegetables. Yet, there are times when just the opposite, that is, lengthy cooking with plentiful water may be desirable to achieve foods such as mild onions. Or again, it may be beneficial to cook with a pan *lid on* since it speeds up cooking or leads to the *desirable* retention of acids, flavor, or nutrients. However, cooking with a*lid on* for the duration of cooking is *detrimental* to the green chlorophyll pigment and *Brassica* flavored vegetables as has been described.

CULINARY ALERT! Cooking produces changes in the turgor, appearance, texture, flavor, and nutritive value. Some changes are desirable, some not. Cook minimally.

FRUITS: UNIQUE PREPARATION AND COOKING PRINCIPLES

In this portion of the chapter, attention is given to some of the unique aspects of cooking and preparing *fruits* (Figure 7.6). Further discussion of "fruits" in this section may include vegetable-fruits such as avocados and peppers, yet most typically, fruit is referring to sweet, fleshy fruits containing seeds. It should be kept in mind that bananas and seedless grapes are examples of *fruits without seeds*.

To repeat a previously mentioned concept, the *botanical* definition of a fruit includes all grains, legumes (beans and peas), nuts, as well as some plant parts commonly eaten as "vegetables" (ie, tomatoes), and thus is different from the culinary definition. According to its *culinary* role, fruit is the sweet, fleshy part of a plant, usually eaten alone or served as dessert. Grains, legumes, and nuts do not fit into this culinary definition of fruit; neither do the "vegetable fruits" such as avocadoes, cucumbers, eggplant, okra, olives, peppers, pumpkin, snap beans, squash, and tomatoes, which are typically considered *vegetables* in dietary regimens. The following is interesting:

> A 1893 tax dispute led to the ruling by the United States Supreme Court that a tomato was a vegetable. "Botanically, tomatoes are considered a fruit of the vine, just as are cucumbers, squashes, beans, and peas. But in common language of people, whether sellers or consumers of provisions, all these are vegetables which are grown in kitchen gardens, and which, eaten cooked or raw, are, like potatoes, carrots, parsnips, turnips, beets, cauliflower, cabbage, celery, and lettuce, usually

FIGURE 7.6 Fruit (courtesy of SYSCO® Incorporated).

served at dinner in, with, or after the soup, fish, or meats which constitute the principal part of the repast, and not like fruits, generally, as dessert" (United States Supreme Court) (8).

Fruit Preparation

During preparation, *water loss* may occur. For example, when fresh-cut strawberries are sprinkled with sugar for added flavor, water is lost from the fruit through osmosis and red liquid can be seen in the bowl of strawberries. Other fruits may show the same effect or undergo *discoloration* due to enzymatic oxidative browning.

Whether by Industry or at home, cooking fruit in different manners may occur as follows:

- **Water**. When fruits are cooked in plain water, water moves into the tissues (***osmosis***) and sugar, at a 12–15% level naturally, diffuses out (***diffusion***). The fruit, including dried fruit such as raisins, becomes plump. Pectins become soluble and diffuse into water; cells become less dense and the product becomes tenderer. Cellulose is softened and lignins remain unchanged. The fruit loses its shape.
- **Sugar Addition**. Sugar may be utilized in cooking. It offers flavor and some preservation. When *large* amounts of sugar (amounts greater than that found naturally in fruits) are added to the cooking water at the *beginning* of cooking, the tenderization is diminished and the *shape* will be *maintained*. This is because the water moves out and the higher concentration of sugar outside of the piece of fruit moves in by diffusion. As well, the sugar interferes with plant pectin solubility. It also dehydrates cellulose and hemicellulose, resulting in shrunken, tough walls. The addition of sugar to fruit *early* in cooking is desirable for berries or slices where shape is important. *Conversely*, when fruits are cooked in plain water and sugar is added *late*, after cooked fruit *loses its shape* and softens, fruit sauces such as applesauce are formed.
- **Flavor Changes**. There are flavor changes that occur in a cooked fruit. Perhaps this is due to the fact that water-soluble sugars and other small molecules escape to the surrounding water. Consequently, the cooked fruit tastes blander unless sugar is added during cooking.

Fruit Juices and Juice Drinks

"Juices" are 100% fruit by definition, while "juice drinks" must contain only 10% or more of real juice. Each may be formulated from a variety of fruits. Data on yield and amounts of produce needed to extract juice becomes important in studies on diet and disease (9). The FDA requires that commercial juices be pasteurized to control microbial growth. Treatment with ultraviolet (UV) irradiation is given in order to reduce the pathogens and other detrimental microorganisms.

Grading

Grading by the United States government (USDA) is a *voluntary* function of packers and processors. It is *not* an indication of safety, nutritive value, or type of packs (eg, sugar and so forth). Wholesalers, commercial, and institutional food service, including restaurants and schools, may purchase according to grade using written specifications, although consumers may be unaware of grading.

Dried and *frozen* forms of fruits and vegetables are graded, but grading indications appear *less* commonly than on *canned* or *fresh* products which often show grade. In the highly competitive wholesale food-service market, *canned* fruits and vegetables receive US Grade A, B, or C.

US Grade A is the *highest* rating and indicates the best appearance and texture, including clarity of liquid, color, shape, size, absence of blemishes or defects, and maturity. US Grade C is the *lowest* grade. *Fresh fruits* and vegetables are rated US Fancy, US No. 1, and US No. 2.

Private labeling by some companies may have specifications that state a narrow range within a grade. Proprietary names may be assigned to various grades.

Organically Grown Fruits and Vegetables

In February 2001, the USDA provided a federal definition for “organically grown” and a federal standard for its production, handling, and processing. Rules for implementing the Organic Foods Production Act of 1990 took several years to go into effect and proposals were released for feedback several years prior to the final ruling. A tremendous amount of public input was obtained in an attempt to satisfy both the organic farmer and the consumer.

The intent of the final comprehensive organic foods standard was to *clarify* the definition for the consumer, as well as to *ease potential confusion* in domestic and export sales, and make use of just *one* product label, eliminating the need for individual state and/or private standards. The USDA Organic Seal also was redesigned for better consumer understanding, and it became effective for use in August 2002.

Subsequent to legislation, foods labeled “organic” must be grown *without* the use of chemical pesticides, herbicides, or fertilizers (10), and must have *verifiable records* of their system of production. Organic products must be 95% organically produced; processed foods may be labeled “made with organic ingredients.” If organic production and handling is *not* followed, yet a product *is* offered for sale as organic, a large monetary fine may be imposed.

Although there is the *absence* of chemical pesticides, herbicides, and fertilizers used during growth, which would be desirable to some individuals, there is *no* evidence that organically grown foods are *higher* in *nutrient* content than conventionally grown foods. A poor soil may yield a lower crop, but *not* one of lesser nutritive value (11).

While the *pesticide* residue would certainly be lowered or nonexistent, *bacterial counts* of organically grown plant material may be *higher* than conventionally grown foods. This is especially true if animal manure was used as a fertilizer and care in washing was overlooked. Organically grown is *not* synonymous with *food safety* either; therefore, as with all produce, care must be taken to wash contaminants off all fruits and vegetables.

It should be noted in this discussion that the National Organic Program (NOP) applies to more than fruits and vegetables. Crop standards, livestock standards, and handling standards are addressed by the act.

BIOTECHNOLOGY (SEE ALSO APPENDICES)

Biotechnology assists in providing a better, less expensive, safer, and tastier food supply (12). Several years of conventional breeding techniques are immensely shortened by gene manipulation, possibly by 50% for some foods (13). Growers have strived to increase availability and yield of their crops, despite factors such as weather conditions in the growing region, insect infestation, and the lengthy time period of conventional breeding.

A combination of (1) conventional breeding by plant breeders including selection, crossing, and mutation, with (2) biotechnology, including recombinant DNA, gene transfer, tissue culture, and plant regeneration (14), produces new germ plasm. This increases production potential and resistance to pests, disease, drought, and pollution while developing more nutritious plant products. Close collaboration between scientists using both approaches is needed in order to improve product quality and meet consumers' demands.

The FDA ensures the safety of genetically altered foods and food ingredients in two ways, regulating: (1) *adulteration*, and (2) by the *food additive* provision of their rules. *Neither* of these regulating methods is different from safety standards of any other nonbioengineered food product (18). Providing human and environmental *safety*, as well as *high-quality* foods is of great significance to public. The FDA requires that all bioengineered foods be labeled *if* they are significantly *different* from the original conventional food in nutritive value or in posing food allergies.

Areas of research continue to focus on improving the areas previously mentioned. Certainly, the nutritive content of plant foods, such as improving the protein content of plants, increasing their resistance to pests, or improving their storage, is researched. In addition to providing the consumer with greater economy, convenience, and improved nutritive value, safety is a factor that is important to both the grower and consumer. *Safety* of biotechnology has been debated and discussed by the public, educators, environmentalists, and scientists. The future may hold more such debate.

The safety of the first genetically engineered food designed for human consumption was demonstrated to the FDA and approval was granted for use of the Flavr-Savr tomato in *May 1994*. Its shelf life is 10 days longer than other tomatoes. Due to the polygalacturonase (PG) enzyme, it stays on the vine *longer*; thus, it can be vine ripened with enhanced flavor. In 1996, the planting of corn, potato, soybeans, and tomato varieties developed through *biotechnology* began following FDA decisions on safety (17). Currently cotton, canola, papaya, squash, and more also are produced. According to the International Food Information Council (IFIC), a significant component of the UnitedStates harvest is produced by biotechnology (IFIC).

Many consumers want to have genetically altered food products so-labeled. Several years ago, surveys showed that "biotechnology is not an issue for most American consumers" (15). A comparable 1998 survey with a cross-section of respondents showed the same or even higher support for biotechnology among Japanese and American consumers (16).

The USDA's Agricultural Research Service (ARS) along with private industry and Academic research centers maintain the goal of developing improved genetic engineering. To date, there are some food companies that have ceased using or announced that they will not use GMOs due to negative consumer reaction. The debate continues.

The Position Statement of the American Dietetic Association regarding biotechnology is as follows: "It is the position of the American Dietetic Association that the techniques of biotechnology are useful in enhancing the quality, nutritional value, and variety of food available for human consumption and in increasing the efficiency of food production, processing, distribution and waste management" (19). "Dietitians can regard the tumultuous public discussions of biotechnology as a source of stress or as an opportunity to become a more valuable resource to consumers" (20).

For a more in-depth report on biotechnology and foods, see the Institute of Food Technologists three-part series titled IFT Expert Report on Biotechnology and Food (19)–(21).

IRRADIATION

Much discussion on irradiation is reported elsewhere in this text (Chapters 17 and 18) and in other writings. Plant seeds may be irradiated to control pathogens. Some fresh fruits, juices, and sprouts also have been treated in this manner. On the horizon are the results of further studies seeking suitable methods to control pathogens in products other than fruit and vegetables.

VEGETARIAN FOOD CHOICES

Vegetables are increasingly used by a growing number of vegetarians in creating purely vegetarian foods (22). Whether it is for religious, political, health, or other reasons, vegetarian foods are selected. In fact, the National Restaurant Association reports that 97% of colleges and universities and 80% of restaurants incorporate vegetarian main dishes into the menus. Some processing companies may offer vegetable flavors as less costly replacements for vegetables in recipe formulations (see Concentrates, Extracts, Oils, Spices, and Herbs. See Chapter 9 for vegetarian diets and protein needs).

In order to meet the needs of vegetarian diets, the number of new products introduced that meet the requirement for vegetarian diets continues to increase.

It is estimated that in the United States, the number of vegetarians may be 24 million people. Yet, only 4% of the general population omits all animal food from their diet, including meat, milk, cheese, and eggs (22).

To clarify "vegetarian" is not simple. One must realize that it may indicate something different to various individuals. The meaning varies. However, true *vegans* are vegetarians who omit animal products from their diet. If other types of vegetarian cuisines are followed, vegetarians might consume milk, or eggs, white meat, or fish.

Since animal products are the only significant source of vitamin B_{12}, vegans need reliable, fortified foods or vitamin B_{12} supplementation in order to maintain the myelin sheath surrounding the nerves and prevent permanent nerve damage and paralysis. It is important to note that microwave heating *inactivates* vitamin B_{12} in foods (23) (Chapter 9).

LABELING OF VEGETABLES AND FRUITS

Nutrition Facts

Vitamin A and C content of foods, along with the minerals calcium and iron, are identified below the solid line on all nutrition facts food labels for products produced in the United States. These nutrients fall short of adequate levels for the population. Many Americans would do well to increase their intake of these two vitamins that are simultaneously so prevalent in fruits and vegetables. The label provides the consumer with information regarding the percentage of daily value that they are consuming in each serving. Individual fresh fruits and vegetables do not have labels, yet supermarket brochures, posters, or plastic bags relate the nutrient contribution.

Label Terms

Labeling terms that apply to fruits and vegetables include the following and must appear as a product descriptor after the product name, for example, "green beans, fresh."

- A "*fresh*" food must be a raw food, alive, and respiring. Some skin surface treatment is acceptable, such as application of wax or pesticides. Treatment with less than one kGy irradiation to inactivate pathogenic and spoilage microorganisms is allowed. (The FDA is considering use of the term "fresh" for alternative nonthermal technologies that function to protect the US food supply and clearly convey food characteristics to consumers.)
- "Freshly prepared" is food that has not been frozen, heat processed, or preserved.
- A "good source of " must contain 10–19% of the daily value of that nutrient per serving.

- If an item states "fat-free," it must have less than 1/2 g of fat per serving. "Low-fat" indicates that the product must contain 3 g of fat or less per serving.
- Calorie level is important to many consumers. If an item states "low-calorie," it must contain less than 40 calories per serving.
- "Sodium-free" signifies that a product contains less than 5 mg of sodium (Na) per serving. "Very-low-sodium" is used for a product that contains less than 35 mg of Na per serving, and "low-sodium" is less than 140 mg Na per serving.
- "High-fiber" is 5 mg or more of fiber per serving.

The 1991 nutrition labeling produce regulations were amended by the FDA. Regulations exist for labeling nutritive value of the 20 most frequently consumed vegetables and fruits (Figures 7.7, 7.8). In addition to the top 20, other vegetables and fruits *must* be labeled if nutritional claims are made. Such labeling is *voluntary* and will continue to be voluntary if there is sufficient compliance noted by the FDA.

NUTRITIVE VALUE OF VEGETABLES AND FRUITS

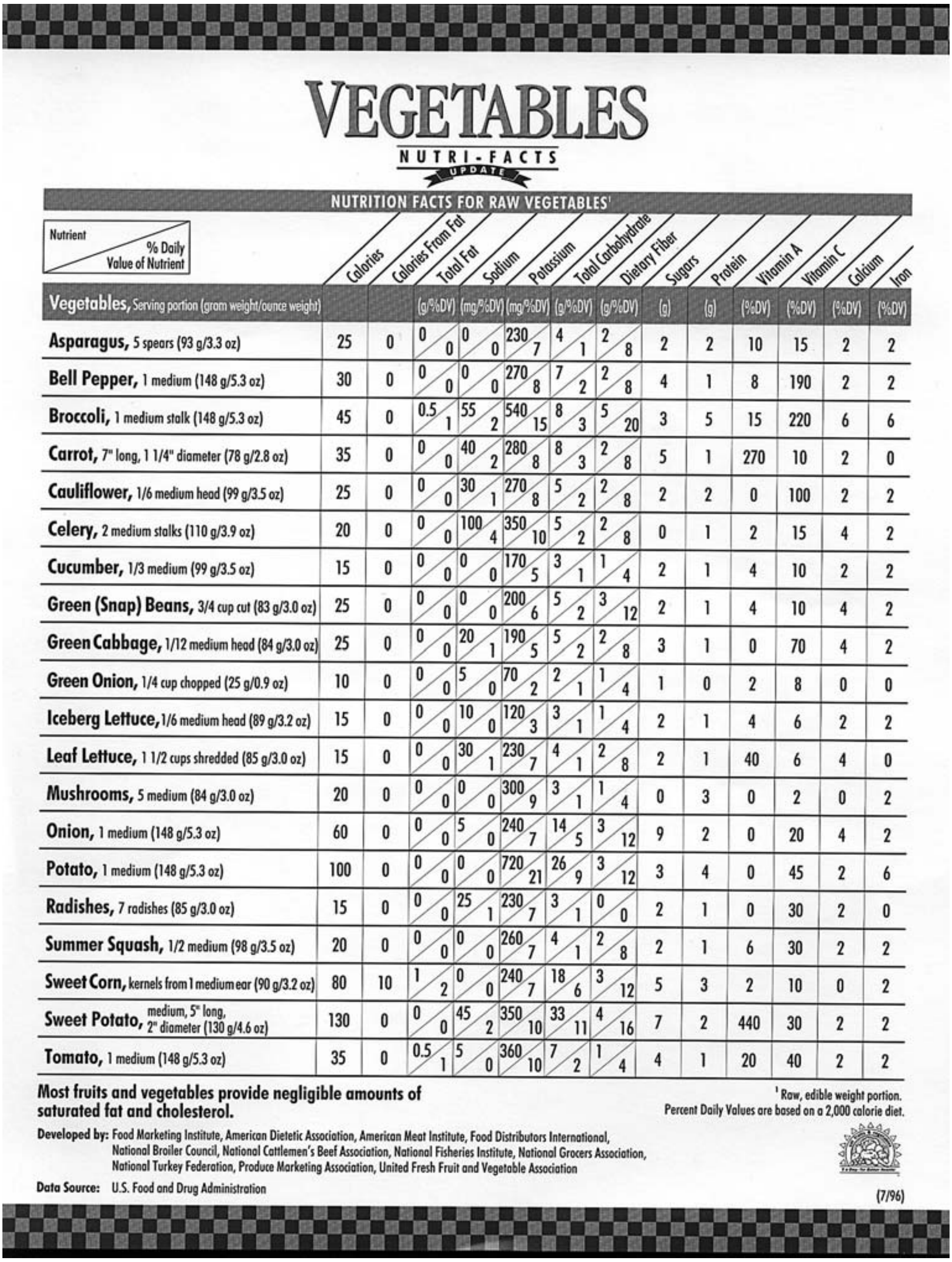
Much information is reported regarding *nutritional value* of vegetables and fruits. Thus, this section is lengthy bringing some nutrition facts forward. Due to a worldwide supply and international purchasing potential, vegetables and fruits have year-round availability. Achieving good nutrition is enhanced by availability of the nutrients present in fruits and vegetables.

Vitamins, notably vitamins A and C, provitamin A (carotene), minerals (calcium and iron), and dietary fiber are among the great benefits of a high fruit and vegetable diet, whether foods are canned, frozen, or fresh. As well, there are antioxidant properties (beta-carotene, vitamin C, and vitamin E) and anticarcinogenic properties, and fat is low for the majority of fruits and vegetables.

Other dietary and medicinal benefits of fruits and vegetables are shown. For example, nonnutrients, such as the ***phytochemicals*** (phyto = plant) in fruits and vegetables, may function in the prevention of human disease. This further supports the idea that nutrition is obtained from food rather than isolated compounds. Isolated compounds of fruits, vegetables, and other foods that are thought to provide health and medicinal benefits to the diet are ***nutraceuticals***. The FDA has not recognized the term "nutraceuticals" or allowed health claims on products beyond those that are supported by the scientific community (Chapter 20, Appendix).

More evaluation and research are needed in order to address the many potential health benefit/disease-preventing properties of plant material. Some nutrition facts are included in Figures 7.7 and 7.8.

Unfortunately, the USDA Department of Health and Human Services has noted: "In this land of plenty, millions of Americans aren't eating wisely. Not because they haven't had enough to eat, but because they eat too many of the wrong things or too little of the right." Fruits and vegetables exert a protective effect against chronic disease. Yet, when servings are counted, only 9% of the



VEGETABLES

NUTRI-FACTS

UPDATE

NUTRITION FACTS FOR RAW VEGETABLES[1]

Nutrient / % Daily Value of Nutrient **Vegetables,** Serving portion (gram weight/ounce weight)	Calories	Calories From Fat	Total Fat (g/%DV)	Sodium (mg/%DV)	Potassium (mg/%DV)	Total Carbohydrate (g/%DV)	Dietary Fiber (g/%DV)	Sugars (g)	Protein (g)	Vitamin A (%DV)	Vitamin C (%DV)	Calcium (%DV)	Iron (%DV)
Asparagus, 5 spears (93 g/3.3 oz)	25	0	0/0	0/0	230/7	4/1	2/8	2	2	10	15	2	2
Bell Pepper, 1 medium (148 g/5.3 oz)	30	0	0/0	0/0	270/8	7/2	2/8	4	1	8	190	2	2
Broccoli, 1 medium stalk (148 g/5.3 oz)	45	0	0.5/1	55/2	540/15	8/3	5/20	3	5	15	220	6	6
Carrot, 7" long, 1 1/4" diameter (78 g/2.8 oz)	35	0	0/0	40/2	280/8	8/3	2/8	5	1	270	10	2	0
Cauliflower, 1/6 medium head (99 g/3.5 oz)	25	0	0/0	30/1	270/8	5/2	2/8	2	2	0	100	2	2
Celery, 2 medium stalks (110 g/3.9 oz)	20	0	0/0	100/4	350/10	5/2	2/8	0	1	2	15	4	2
Cucumber, 1/3 medium (99 g/3.5 oz)	15	0	0/0	0/0	170/5	3/1	1/4	2	1	4	10	2	2
Green (Snap) Beans, 3/4 cup cut (83 g/3.0 oz)	25	0	0/0	0/0	200/6	5/2	3/12	2	1	4	10	4	2
Green Cabbage, 1/12 medium head (84 g/3.0 oz)	25	0	0/0	20/1	190/5	5/2	2/8	3	1	0	70	4	2
Green Onion, 1/4 cup chopped (25 g/0.9 oz)	10	0	0/0	5/0	70/2	2/1	1/4	1	0	2	8	0	0
Iceberg Lettuce, 1/6 medium head (89 g/3.2 oz)	15	0	0/0	10/0	120/3	3/1	1/4	2	1	4	6	2	2
Leaf Lettuce, 1 1/2 cups shredded (85 g/3.0 oz)	15	0	0/0	30/1	230/7	4/1	2/8	2	1	40	6	4	0
Mushrooms, 5 medium (84 g/3.0 oz)	20	0	0/0	0/0	300/9	3/1	1/4	0	3	0	2	0	2
Onion, 1 medium (148 g/5.3 oz)	60	0	0/0	5/0	240/7	14/5	3/12	9	2	0	20	4	2
Potato, 1 medium (148 g/5.3 oz)	100	0	0/0	0/0	720/21	26/9	3/12	3	4	0	45	2	6
Radishes, 7 radishes (85 g/3.0 oz)	15	0	0/0	25/1	230/7	3/1	0/0	2	1	0	30	2	0
Summer Squash, 1/2 medium (98 g/3.5 oz)	20	0	0/0	0/0	260/7	4/1	2/8	2	1	6	30	2	2
Sweet Corn, kernels from 1 medium ear (90 g/3.2 oz)	80	10	1/2	0/0	240/7	18/6	3/12	5	3	2	10	0	2
Sweet Potato, medium, 5" long, 2" diameter (130 g/4.6 oz)	130	0	0/0	45/2	350/10	33/11	4/16	7	2	440	30	2	2
Tomato, 1 medium (148 g/5.3 oz)	35	0	0.5/1	5/0	360/10	7/2	1/4	4	1	20	40	2	2

Most fruits and vegetables provide negligible amounts of saturated fat and cholesterol.

[1] Raw, edible weight portion.
Percent Daily Values are based on a 2,000 calorie diet.

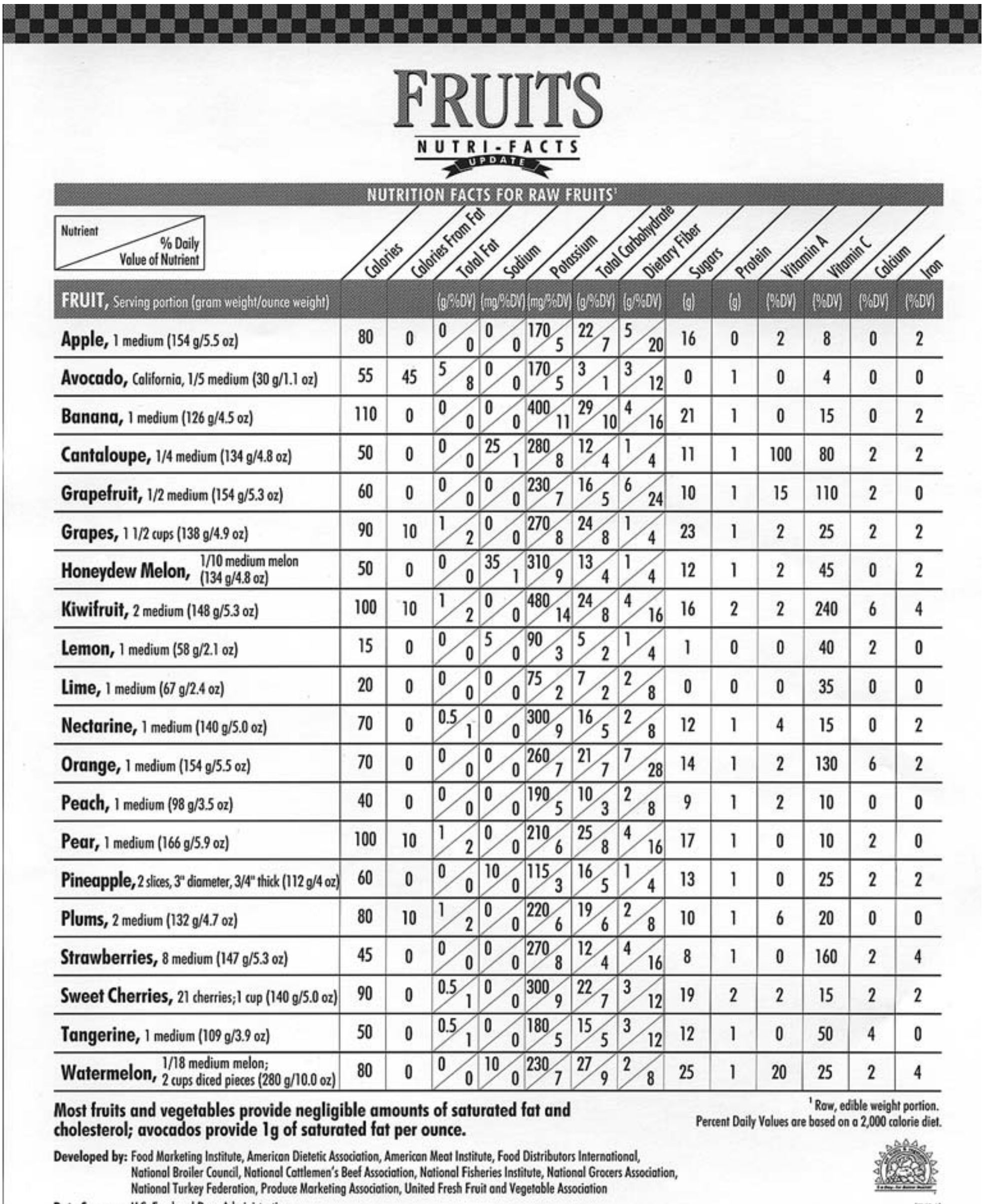
Developed by: Food Marketing Institute, American Dietetic Association, American Meat Institute, Food Distributors International, National Broiler Council, National Cattlemen's Beef Association, National Fisheries Institute, National Grocers Association, National Turkey Federation, Produce Marketing Association, United Fresh Fruit and Vegetable Association

Data Source: U.S. Food and Drug Administration

(7/96)

FIGURE 7.7 Vegetables nutrifacts (Data Source: US Food and Drug Administration. *Developed by:* Food Marketing Institute et al.).

population is reported to have met the guidelines according to a National Health and Nutrition Examination Survey (NHANES II) (24). According to the American Diabetic Association Exchange List, one serving of vegetables contains 25 calories and one serving of fruit contains 60 calories.



FRUITS

NUTRI-FACTS

UPDATE

NUTRITION FACTS FOR RAW FRUITS¹

Nutrient / % Daily Value of Nutrient

FRUIT, Serving portion (gram weight/ounce weight)	Calories	Calories From Fat	Total Fat (g/%DV)	Sodium (mg/%DV)	Potassium (mg/%DV)	Total Carbohydrate (g/%DV)	Dietary Fiber (g/%DV)	Sugars (g)	Protein (g)	Vitamin A (%DV)	Vitamin C (%DV)	Calcium (%DV)	Iron (%DV)
Apple, 1 medium (154 g/5.5 oz)	80	0	0/0	0/0	170/5	22/7	5/20	16	0	2	8	0	2
Avocado, California, 1/5 medium (30 g/1.1 oz)	55	45	5/8	0/0	170/5	3/1	3/12	0	1	0	4	0	0
Banana, 1 medium (126 g/4.5 oz)	110	0	0/0	0/0	400/11	29/10	4/16	21	1	0	15	0	2
Cantaloupe, 1/4 medium (134 g/4.8 oz)	50	0	0/0	25/1	280/8	12/4	1/4	11	1	100	80	2	2
Grapefruit, 1/2 medium (154 g/5.3 oz)	60	0	0/0	0/0	230/7	16/5	6/24	10	1	15	110	2	0
Grapes, 1 1/2 cups (138 g/4.9 oz)	90	10	1/2	0/0	270/8	24/8	1/4	23	1	2	25	2	2
Honeydew Melon, 1/10 medium melon (134 g/4.8 oz)	50	0	0/0	35/1	310/9	13/4	1/4	12	1	2	45	0	2
Kiwifruit, 2 medium (148 g/5.3 oz)	100	10	1/2	0/0	480/14	24/8	4/16	16	2	2	240	6	4
Lemon, 1 medium (58 g/2.1 oz)	15	0	0/0	5/0	90/3	5/2	1/4	1	0	0	40	2	0
Lime, 1 medium (67 g/2.4 oz)	20	0	0/0	0/0	75/2	7/2	2/8	0	0	0	35	0	0
Nectarine, 1 medium (140 g/5.0 oz)	70	0	0.5/1	0/0	300/9	16/5	2/8	12	1	4	15	0	2
Orange, 1 medium (154 g/5.5 oz)	70	0	0/0	0/0	260/7	21/7	7/28	14	1	2	130	6	2
Peach, 1 medium (98 g/3.5 oz)	40	0	0/0	0/0	190/5	10/3	2/8	9	1	2	10	0	0
Pear, 1 medium (166 g/5.9 oz)	100	10	1/2	0/0	210/6	25/8	4/16	17	1	0	10	2	0
Pineapple, 2 slices, 3" diameter, 3/4" thick (112 g/4 oz)	60	0	0/0	10/0	115/3	16/5	1/4	13	1	0	25	2	2
Plums, 2 medium (132 g/4.7 oz)	80	10	1/2	0/0	220/6	19/6	2/8	10	1	6	20	0	0
Strawberries, 8 medium (147 g/5.3 oz)	45	0	0/0	0/0	270/8	12/4	4/16	8	1	0	160	2	4
Sweet Cherries, 21 cherries;1 cup (140 g/5.0 oz)	90	0	0.5/1	0/0	300/9	22/7	3/12	19	2	2	15	2	2
Tangerine, 1 medium (109 g/3.9 oz)	50	0	0.5/1	0/0	180/5	15/5	3/12	12	1	0	50	4	0
Watermelon, 1/18 medium melon; 2 cups diced pieces (280 g/10.0 oz)	80	0	0/0	10/0	230/7	27/9	2/8	25	1	20	25	2	4

Most fruits and vegetables provide negligible amounts of saturated fat and cholesterol; avocados provide 1g of saturated fat per ounce.

¹ Raw, edible weight portion.
Percent Daily Values are based on a 2,000 calorie diet.

Developed by: Food Marketing Institute, American Dietetic Association, American Meat Institute, Food Distributors International, National Broiler Council, National Cattlemen's Beef Association, National Fisheries Institute, National Grocers Association, National Turkey Federation, Produce Marketing Association, United Fresh Fruit and Vegetable Association

Data Source: U.S. Food and Drug Administration

(7/96)

FIGURE 7.8 Fruits Nutri-Facts (Data Source: US Food and Drug Administration. Developed by: Food Marketing Institute et al.).

"Vary your veggies" and "focus on fruits" is the USDA advice in selecting vegetables and fruits as part of a healthy diet. If following a 2000-calorie diet, 2 1/2 cups of vegetables plus 2 cups of fruit per day are recommended. Examples are shown in Figure 7.1. Americans have made positive dietary changes in the past 20 years, including increasing fruits, vegetables, and grains; yet they still fail to reach the appropriate number of servings of fruits, dark green leafy vegetables, deep yellow vegetables, dried beans, and other legumes (25).

Citrus fruits provide protection against cancer, heart disease, and neural tube defects (26). They contain limonene and phenols that block formation of nitrosamines and facilitate carcinogen excretion from the body. In addition, citrus fruits contain antioxidants, vitamin C, and relatively good amounts of folic acid which has been shown to prevent reoccurrence of neural tube defect in pregnant women.

Membranes and juice sacs of fruit contain pectin, unless removed in processing. Several possible dietary benefits of this fiber include glycemic, cholesterol, and cancer control (27). The FDA allows a label claim regarding foods with dietary fiber and a reduction of cancer incidence.

Taste is the most important factor that influences food choices; positive messages about benefits of diets with plenty of fruits and vegetables help with making choices (28). On a regular basis, the American public eats too few fruits and vegetables containing nutrients, such as vitamins A and C (on all nutrition facts labels) or the antioxidant vitamin E, all of which have an important role in preventing or delaying major degenerative diseases of Americans (29).

The American Dietetic Association states that eating a wide variety of foods, including an emphasis on grains, vegetables, and fruits, is the best way to obtain adequate amounts of beneficial food constituents: "It is the position of The American Dietetic Association that the best nutritional strategy for promoting optimal health and reducing the risk of chronic disease is to obtain adequate nutrients from a variety of foods. Vitamin and mineral supplementation is appropriate when well-accepted, peer-reviewed scientific evidence shows safety and effectiveness" (30).

According to "Shopping for Health 2000" survey by the Food Marketing Institute/Prevention, the following factors motivate purchase decisions: general health (95%), fat (82%), doctor (70%), cholesterol (72%), lower risk (72%), avoid additives/preservatives (68%), manage/treat (58%), food intolerance (49%), and slow aging (48%) (31).

It is interesting to note that The American Dental Association recommends eating fruits such as apples and oranges and many uncooked vegetables such as carrots and celery. These act as "detergent" foods, cleaning teeth and gums of food debris that may otherwise lead to the major nutrition-related problem of tooth decay.

Nutrient Losses

Losses may result from:

- Ascorbic acid (vitamin C) and thiamin (B_1) diffused to the water and oxidized.
- Mineral salts lost in soaking or cooking water.
- Excessive peel removal.

- Result of excessive chopping.
- Prolonged or high temperature storage.

Storage:

- Succulents and leafy fruits and vegetables, stored covered in the refrigerator.
- Tubers, stored in a dark, cool place for quality.

SAFETY OF VEGETABLES AND FRUITS

The public is encouraged to eat more fruits and vegetables for health. They expect foods to be safe. Fruits and vegetables are *not* considered “potentially hazardous foods” that allow the “rapid and progressive growth of infectious or toxigenic microorganisms” (Model FDA Food Code).

In comparison to animal-based foods, there are few problems with plant-based products, but unfortunately they can carry disease. Recently fresh, bagged spinach was pulled off the market nationwide due to *Escherichia coli* bacteria. Health Departments across the United States advised that washing the bagged spinach could not guarantee safety. One death and illnesses in many states followed ingestion of the spinach.

Pathogenic microorganisms are found in the environment and can contaminate food, causing illness. Of serious concern are *Salmonella, E. coli 0157:H7, Campylobacter, Listeria, Staphylococcus aureus, Shigella, Clostridium botulinum, Bacillus cereus, and Hepatitis A*, to name a few (see Chapter 16) (32). *Salmonella* bacteria have been found on cantaloupe, watermelon, and tomatoes, *Listeria* on cabbage, and *Campylobacte*r on mushrooms (33). Imports from less-developed regions of the world may be implicated as a contributing factor in the increase in fruit- and vegetable-related foodborne illness.

Regardless of its source, it is recommended that “ready-to-eat” value-added fresh produce be *washed* prior to consumption and then refrigerated in order to maintain food safety. Washing is recommended despite the label statement that the product is washed and ready-to-eat.

Cross-contamination from other foods, such as meats, should be avoided, pull dates should be adhered to, and assembly/preparation areas should be sanitary. Of course, personal hygiene is crucial to food safety.

Various antimicrobials are used in industry to improve the safety of fruits and vegetables, This is especially true in the growing market for minimally processed fruits and vegetables. Chlorine has proven to be *less* than effective in limiting growth of some bacteria, eg, *Listeria monocytogenes*, and therefore hydrogen peroxide (H_2O_2) disinfection has been considered. *Chlorine dioxide, hydrogen peroxide* (H_2O_2), and *ozone* may be useful in reducing the microbial load on some fruits and vegetables, the last two leaving no residues following treatment. Peroxyacetic acid also may be used.

Hydrogen peroxide is a generally recognized as safe substance that also has been used as a bleaching agent (as in milk used for cheese) and as an antimicrobial agent in foods (34). Some antimicrobials are effective due to their low pH, but are not usable due to the unacceptable flavor that they impart. Other substances having antimicrobial properties include essential oils from citrus, coriander, mint, parsley, and vanillin juice peels.

Overall, the use of such antimicrobial chemicals are most effective when coupled with the following: good washing, high-intensity pulsed light, irradiation, ultra-violet light, good manufacturing practices, and hazard analysis and critical control points (HACCP) principles. These practices contribute to ensuring safety in fresh produce (32).

Precautions against contamination and growth of harmful bacteria include the following (33):

- Buying only what is necessary for short-term needs; longer storage allows multiplication of any bacteria that are present.
- Careful washing of hands before handling fresh produce (even after holding a public banister or door knob) and between cutting and eating fresh produce.
- Rinsing produce to remove harmful bacteria prior to consumption (even uneaten, disposed of rinds) and after removing outer leaves and peels.
- Refrigerate leftovers to slow any bacterial growth.
- Prepare fruits and vegetables on sanitary work surfaces with sanitary utensils.

The FDA recommends that where feasible products must be cooked after the addition of spices in order to destroy microorganisms, although commercial processing of herbs, spices, and their extracts reduces bacterial count. It bears repeating that *personal hygiene* standards should be high in order to minimize the incidence of food contamination. As well, juices should be pasteurized to *eliminate E. coli 0157:H7*, which may be carried to the fruit by fecal contamination or improper handling.

CONCLUSION

Plant tissue is composed primarily of parenchyma tissue. The structure and composition of a fresh fruit or vegetable changes as the cell is destroyed. As fruits and vegetables typically contain a very large percentage of water, the maintenance of turgor pressure is an important factor in determining plant material quality.

The desirable pigments and flavor compounds contained in fruits and vegetables may undergo unacceptable changes upon preparation and cooking. Discoloration of some cut vegetables or fruit is known as enzymatic oxidative browning, which must be controlled. Improper storage or cooking can result in quality losses.

The nutritive value of vitamins, provitamins (carotene) minerals, fiber, and other compounds contained in fruits and vegetables are extremely important to the diet, and there are medicinal benefits of fruits and vegetables. Many are low in fat content. Vegetarian food choices may be met with consumption of a variety of fruits and vegetables. "Vary your veggies" and "focus on fruits" is the USDA advice in selecting vegetables and fruits as part of a healthy diet.

Biotechnology provides the consumer with greater economy and convenience. Coupled with an understanding of the role of phytochemicals in disease prevention, vegetables and fruits may provide a greater nutrient contribution to the human diet. Irradiation is utilized as a means of ensuring food safety.

A specialty produce supplier has said, "Produce is a living commodity, forever changing, with new items appearing every year" (35). Fruits and vegetables require special handling to maintain high quality. Items of high nutritional value that were once unfamiliar and not used, as well as new items from around the world, are now available on grocery shelves.

GLOSSARY

Allium: Flavor compounds in the genus *Allium* that contain sulfur compounds and offer phytochemical value.

Anthocyanin: Red-blue pigmented vegetables of the flavone family.

Anthoxanthin: Whitish pigmented fruits and vegetables of the flavone group of chemicals.

Biotechnology: Biogenetic engineering of animals, microorganisms, and plants to alter or create products that have increased resistance to pests and improved nutritive value and shelf life.

Brassica: Flavor compound of *Brassica* genus including cruciferous vegetables with sulfur compounds.

Carotenoid: The group of red-orange pigmented fruits and vegetables; some are precursors of vitamin A and also have antioxidant value.

Cellulose: Glucose polymer joined by β-1,4 glycosidic linkages; cannot be digested by human enzymes, thus it provides insoluble dietary fiber.

Cell sap: Found in the plant vacuole; contains water-soluble components such as sugars, salts, and some color and flavor compounds.

Chlorophyll: The green pigment of fruits and vegetables.

Cytoplasm: Plant cell contents inside the cell membrane, but outside the nucleus.

Diffusion: Movement of solute across a permeable membrane from an area of greater concentration to lesser concentration in heated products that do not have an intact cell membrane.

Enzymatic oxidative browning: Browning of cut or bruised fruits and vegetables due to the presence of phenolic compounds, enzymes, and oxygen.

Fresh: Alive and respiring as evidenced by metabolic and biochemical activities.

Fruit: The mature ovaries of plants with their seeds.

Hemicellulose: The indgestible fiber in cell walls that provides bulk in the diet; may be soluble, but primarily insoluble.

Lignin: The noncarbohydrate component of fiber of plant tissue that is insoluble and excreted from the body. It provides the undesirable woody texture of mature plants.

Middle lamella: The cementing material between adjacent plant cells, containing pectic substances, magnesium, calcium, and water.

Nutraceuticals: The name given to a proposed new regulatory category of food components that may be considered a food or part of a food and may supply medical or health benefits including the treatment or prevention of disease. A term not recognized by the FDA.

Osmosis: The movement of water across semipermeable membranes from an area of greater concentration to lesser concentration in products with an intact cell membrane.

Parenchyma tissue: Majority of plant cells containing the cytoplasm and nucleus.

Pectic substances: The intercellular "cement" between cell walls; the gel-forming polysaccharide of plant tissue.

Phytochemicals: Plant chemicals; natural compounds other than nutrients in fresh plant material that help in disease prevention. They protect against oxidative cell damage and may facilitate carcinogen excretion from the body to reduce the risk of cancer.

Turgor pressure: Pressure exerted by water-filled vacuoles on the cytoplasm and the partially elastic cell wall.

Vacuole: Cavity filled with cell sap and air.

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PART III

Proteins

CHAPTER 8

Proteins in Food: An Introduction[1]

Introduction

Proteins are the most abundant molecules in cells, making up 50% or more of their dry weight. Every protein has a unique structure and conformation or shape, which enables it to carry out a specific function in a living cell. Proteins comprise the complex muscle system and the connective tissue network, and they are important as carriers in the blood system. All enzymes are proteins; enzymes are important as catalysts for many reactions (both desirable and undesirable) in foods.

All proteins contain carbon, hydrogen, nitrogen, and oxygen. Most proteins contain sulfur and some contain additional elements; for example, milk proteins contain phosphorus and hemoglobin and myoglobin contain iron. Copper and zinc also are constituents of some proteins.

Proteins are made up of amino acids. There are at least 20 different amino acids found in nature, and they have different properties depending on their structure and composition. When combined to form a protein, the result is a unique and complex molecule with a characteristic structure and conformation and a specific function in the plant or animal where it belongs. Small changes, such as a change in pH or simply heating a food, can cause dramatic changes in protein molecules. Such changes are seen, for example, when cottage cheese is made by adding acid to milk or when scrambled eggs are made by heating and stirring eggs.

Proteins are very important in foods, both nutritionally and as functional ingredients. They play an important role in determining the texture of a food. They are complex molecules, and it is important to have an understanding of the basics of protein structure to understand the behavior of many foods during processing. This chapter covers the basics of amino acid and protein structure. Individual proteins, such as milk, meat, wheat, and egg proteins, are covered in the chapters relating to these specific foods.

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[1] For use with subsequent Protein food chapters

AMINO ACIDS

General Structure of Amino Acids

Every ***amino acid*** contains a central carbon atom to which is attached a carboxyl group (COOH), an amino group (NH_2), a hydrogen atom, and another group or side chain R specific to the particular amino acid. The general formula for

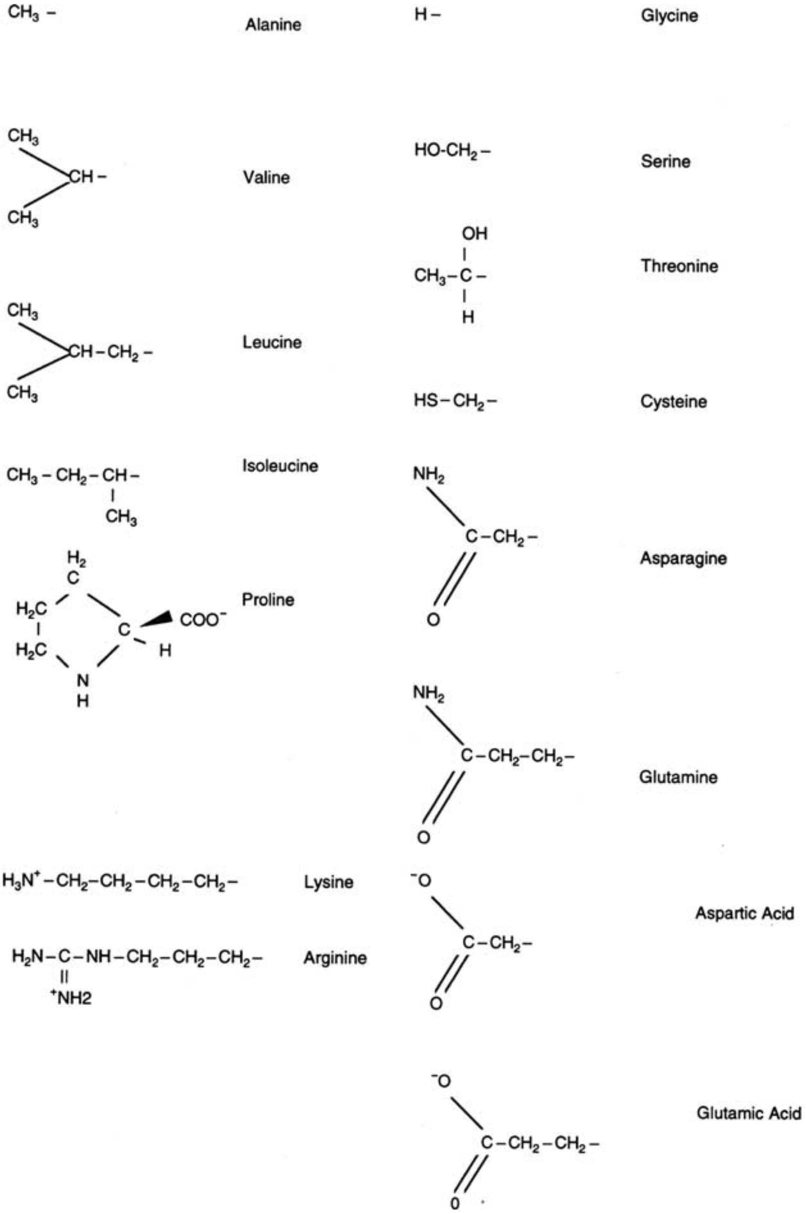


FIGURE 8.1 Examples of amino acids classified according to the nature of their R groups (only the side groups are shown).

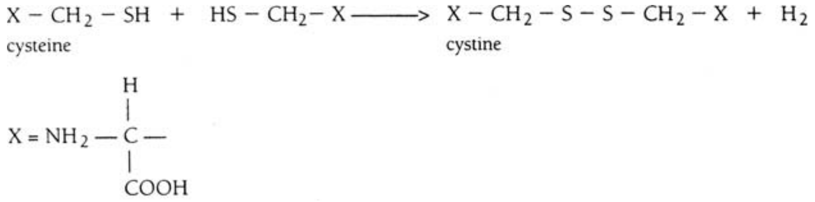
an amino acid is Glycine is the simplest amino acid, with the R group being a hydrogen atom. There are more than 20 different amino acids in proteins. Their properties depend on the nature of their side chains or R groups.

In a solution at pH 7, all amino acids are ***zwitterions;*** that is, the amino group and carboxyl groups are both ionized and exist as COO^- and NH_3^+, respectively. Therefore, amino acids are ***amphoteric*** and can behave as an acid or as a base in water depending on the pH. When acting as an acid or proton donor, the positively charged amino group donates a hydrogen ion, and when acting as a base, the negatively charged carboxyl group gains a hydrogen ion, as follows.

Categories of Amino Acids

Amino acids can be divided into four categories, according to the nature of their side chains, as shown in Figure 8.1. The first category includes all the amino acids with ***hydrophobic*** or **nonpolar** side chains. The hydrophobic (water-hating) amino acids contain a hydrocarbon side chain. Alanine is the simplest one, having a methyl group (CH_3) as its side chain. Valine and leucine contain longer, branched, hydrocarbon chains. Proline is an important nonpolar amino acid. It contains a bulky five-membered ring, which interrupts ordered protein structure. Methionine is a sulfur-containing nonpolar amino acid. The nonpolar amino acids are able to form hydrophobic interactions in proteins; that is, they associate with each other to avoid association with water.

The second group of amino acids includes those with **polar uncharged** side chains. This group is ***hydrophilic***. Examples of amino acids in this group include serine, glutamine, and cysteine. They contain either a hydroxyl group (OH), an amide group ($CONH_2$), or a thiol group (SH). All polar amino acids can form hydrogen bonds in proteins. Cysteine is unique because it can form ***disulfide bonds*** (–S–S–), as shown below:



$$\underset{\text{cysteine}}{X - CH_2 - SH} + HS - CH_2 - X \longrightarrow \underset{\text{cystine}}{X - CH_2 - S - S - CH_2 - X} + H_2$$

$$X = NH_2 - \overset{\displaystyle H}{\underset{\displaystyle COOH}{\overset{|}{\underset{|}{C}}}} -$$

A disulfide bond is a strong covalent bond, unlike hydrogen bonds, which are weak interactions. Two molecules of cysteine can unite in a protein to form a disulfide bond. A few disulfide bonds in a protein have a significant effect on protein structure, because they are strong bonds. Proteins containing disulfide bonds usually are relatively heat stable and more resistant to unfolding than other proteins. The presence of cysteine in a protein therefore tends to have a significant effect on protein conformation.

The third and fourth categories of amino acids include the charged amino acids. The **positively charged (basic)** amino acids include lysine, arginine, and histidine. These are positively charged at pH 7 because they contain an extra amino group. When a basic amino acid is part of a protein, this extra amino group is free (in other words, not involved in a peptide bond) and depending on the pH may be positively charged.

The **negatively charged (acidic)** amino acids include aspartic acid and glutamic acid. These are negatively charged at pH 7 because they both contain an extra carboxyl group. When an acidic amino acid is contained within a protein, the extra carboxyl group is free and may be charged, depending on the pH.

Oppositely charged groups are able to form ionic interactions with each other. In proteins, acidic and basic amino acid side chains may interact with each other, forming ionic bonds or salt bridges.

PROTEIN STRUCTURE AND CONFORMATION

All proteins are made up of many amino acids joined by ***peptide bonds***. Peptide bonds are strong bonds and are not easily disrupted. A ***dipeptide*** contains two amino acids joined by a peptide bond. A ***polypeptide*** contains several amino acids joined by peptide bonds. Proteins are usually much larger molecules, containing several hundred amino acids. They can be hydrolyzed, yielding smaller polypeptides, by enzymes or by acid digestion.

The sequence of amino acids joined by peptide bonds forms the backbone of a protein:

- The protein backbone consists of repeating N–C–C units.
- The amino acid side chains (R groups) project alternately from either side of the protein chain.
- The nature of the R groups determines the structure or ***conformation*** of the chain. (In other words, the shape the protein assumes in space.)

Each protein has a complex and unique conformation, which is determined by the specific amino acids and the sequence in which they occur along the chain. To understand the function of proteins in food systems and the changes that occur in proteins during processing, it is important to understand the basics of protein structure. Proteins are described as having four types of structure—primary, secondary, tertiary, and quaternary structure—and these build on each other. The primary structure determines the secondary structure and so on. The different types of protein structures are outlined below.

Primary Structure

The primary structure (***protein primary structure***) of a protein is the specific sequence of amino acids joined by peptide bonds along the protein chain. This is the simplest way of looking at protein structure. In reality, proteins do not exist simply as straight chains. However, it is the specific sequence of amino acids that determines the form or shape that a protein assumes in space. Therefore, it is essential to know the primary structure if a more detailed understanding of the structure and function of a particular protein is desired.

Secondary Structure

The secondary structure (***protein secondary structure***) of a protein refers to the three-dimensional organization of segments of the polypeptide chain. Important secondary structures include the following:

- Alpha helix: ordered structure.
- Beta pleated sheet: ordered structure.
- Random coil: disordered structure.

The ***alpha* (α) *helix*** is a corkscrew structure, with 3.6 amino acids per turn. It is shown in Figure 8.2. It is stabilized by intrachain hydrogen bonds; that is, the hydrogen bonds occur within a single protein chain, rather than between adjacent chains. Hydrogen bonds occur between each turn of the helix. The oxygen and hydrogen atoms that comprise the peptide bonds are involved in hydrogen bond formation. The α-helix is a stable, organized structure. It cannot be formed if proline is present, because the bulky five-membered ring prevents formation of the helix.

The ***beta* (β) *pleated sheet*** is a more extended conformation than the α-helix. It can be thought of as a zigzag structure rather than a corkscrew. It is shown in Figure 8.3. The stretched protein chains combine to form β-pleated sheets. These sheets are linked together by interchain hydrogen bonds. (Interchain hydrogen bonds occur between adjacent sections of the protein chains rather than within an individual chain.) Again, the hydrogen and oxygen atoms that form the peptide bonds are involved in hydrogen bond formation. Like the α-helix, the β-pleated sheet also is an ordered structure.

The ***random coil*** is a secondary structure with no regular or ordered pattern along the polypeptide chain. This is a much more flexible structure than either the α-helix or β-pleated sheet. It is formed when amino acid side chains prevent formation of the α-helix or β-sheet. This may occur if proline is present or if there are highly charged regions within the protein.

A protein may contain regions of α-helix, β-sheet, and random coil at different places along the chain. How much of each type of secondary structure it contains

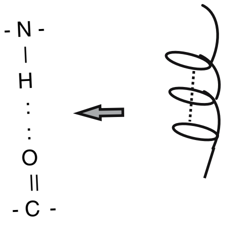


FIGURE 8.2 Schematic three-dimensional structure of an α-helix.

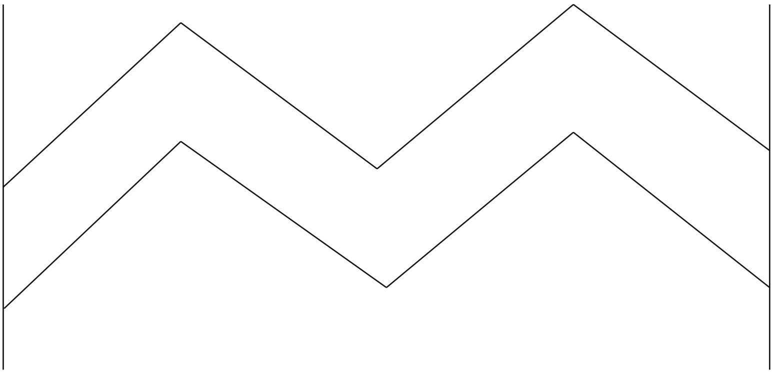


FIGURE 8.3 Schematic three-dimensional structure of β-pleated sheets.

depends on the sequence of amino acids or, in other words, on the primary structure of the protein.

Tertiary Structure

The ***tertiary structure*** of a protein refers to the three-dimensional organization of the complete protein chain. In other words, it refers to the spatial arrangement of a protein chain that contains regions of α-helix, β-sheet, and random coil. So, this structure is really an overview of a protein chain rather than a detailed look at a small section of it. Again, the tertiary structure is built on the secondary structure of a specific protein.

There are two types of protein tertiary structure:

- Fibrous proteins
- Globular proteins

Fibrous proteins include structural proteins such as collagen (connective tissue protein) or actin and myosin, which are the proteins that are responsible for muscle contraction. The protein chains are extended, forming rods or fibers. Proteins with a fibrous tertiary structure contain a large amount of ordered secondary structure (either α-helix or β-sheet).

Globular proteins are compact molecules and are spherical or elliptical in shape, as their name suggests. These include transport proteins, such as myoglobin, which carry oxygen to the muscle. The whey proteins and the caseins, both of which are milk proteins, also are globular proteins. Globular tertiary structure is favored by proteins with a large number of hydrophobic amino acids. These orient toward the center of the molecule and interact with each other by hydrophobic interactions. Hydrophilic amino acids orient toward the outside of the molecule and interact with other molecules; for example, they may form hydrogen bonds with water. The orientation of the hydrophobic amino acids toward the center of the molecule produces the compact globular shape that is characteristic of globular proteins.

Quaternary Structure

Protein quaternary structure, or the quaternary protein structure, involves the noncovalent association of protein chains. The protein chains may or may not be identical. Examples of quaternary structure include the actomyosin system of muscles and the casein micelles of milk. For more information on these structures, the reader is referred to the chapters on meat and milk, respectively.

Interactions Involved in Protein Structure and Conformation

Protein primary structure involves only peptide bonds, which link the amino acids together in a specific and unique sequence. Secondary and tertiary structures may be stabilized by hydrogen bonds, disulfide bonds, hydrophobic interactions, and ionic interactions. ***Steric*** or spatial effects also are important in determining protein conformation. The space that a protein molecule occupies is determined partially by the size and shape of the individual amino acids along the protein chain. For example, bulky side chains such as proline prevent formation of the α-helix and favor random coil formation. This prevents the protein from assuming certain arrangements in space.

Quaternary structures are stabilized by the same interactions, with the exception of disulfide bonds. As already has been mentioned, disulfide bonds are strong, covalent bonds and so only a few disulfide bonds will have a dramatic effect on protein conformation and stability. Hydrogen bonds, on the other hand, are weak bonds, but they are important because there are so many of them.

Each protein takes on a unique native conformation in space, which almost can be considered as a "fingerprint." As already has been mentioned, the exact folding of the protein into its natural conformation is governed by the amino acids that are present in the protein and the bonds that the side chains are able to form in a protein. The amino acid sequence also is important, as the location of the amino acids along the chain determines which types of bonds will be formed and where, and thus determines how much α-helix, β-sheet, or random coil will be present in a protein. This, in turn, determines the tertiary and quaternary structure of a protein, all of which combine to define its native conformation. Knowledge of protein conformation and stability is essential to understanding the effects of processing on food proteins.

REACTIONS AND PROPERTIES OF PROTEINS

Amphoteric

Like amino acids, proteins are ***amphoteric*** (being able to act as an acid or a base) depending on the pH. This enables them to resist small changes in pH. Such molecules are said to have buffering capacity.

Isoelectric Point

The ***isoelectric point*** of a protein is the pH at which the protein is electrically neutral (it is denoted by pI). At this pH, the global or overall charge on the protein is zero. This does not mean that the protein contains no charged groups. It means that the number of positive charges on the protein is equal to the number of negative charges. At the isoelectric point, the protein molecules usually precipitate because they do not carry a net charge. (Molecules that carry a like charge repel each other, and thus form a stable dispersion in water. Removal of the charge removes the repulsive force and allows the molecules to interact with each other and precipitate, in most cases.)

The pH of the isoelectric point differs for each protein. It depends on the ratio of free ionized carboxyl groups to free ionized amino groups in the protein.

The isoelectric point is important in food processing. For example, cottage cheese is made by adding lactic acid to milk to bring the pH to the isoelectric point of the major milk proteins (the caseins). The proteins precipitate at this pH, forming curds. These are separated from the rest of the milk and may be pressed and/or mildly salted before being packaged as cottage cheese.

Water-Binding Capacity

Water molecules can bind to the backbone and to polar and charged side chains of a protein. Depending on the nature of their side chains, proteins may bind varying amounts of water—they have a ***water-binding capacity***. Proteins with many charged and polar groups bind water readily, whereas proteins with many hydrophobic groups do not bind much water. As proteins get closer to their isoelectric point, they tend to bind less water, because reduced charge on the protein molecules results in reduced affinity for water molecules.

The presence of bound water helps to maintain the stability of a protein dispersion. This is due to the fact that the bound water molecules shield the protein molecules from each other. Therefore, they do not associate with each other or precipitate as readily, and so the dispersion tends to be more stable.

Salting-In and Salting-Out

Some proteins cannot be dispersed in pure water but are readily dispersed in dilute salt solutions. When a salt solution increases the dispersibility of a protein, this is termed "**salting-in**." It occurs because charged groups on a protein bind the anions and cations of the salt solution more strongly than water. The ions, in turn, bind water; thus, the protein is dispersed in water more easily.

Salting-in is important in food processing. For example, brine may be injected into ham to increase the dispersibility of the proteins. This has the effect of increasing their water-binding capacity, and so the ham is moister and its weight is increased. The same is true for poultry to which polyphosphates are added.

Salting-out occurs at high salt concentrations, when salts compete with the protein for water. The result is that there is insufficient water available to bind to the protein, and so the protein precipitates. This is not normally a problem in food processing. However, it may be a contributing factor to the deterioration of food quality during freezing of foods; during the freezing process, water is effectively removed as ice crystals, and so the concentration of liquid water decreases and the solute concentration increases dramatically. This is discussed in Chapter 17.

Denaturation

Denaturation is the change in the secondary, tertiary, and or quaternary structure of a protein. There is no change in the primary structure. In other words, denaturation does not involve breaking of peptide bonds. The protein unfolds, but there is no change in its amino acid sequence. Denaturation may occur as a result of the following:

- Heat
- pH change
- Ionic strength change (changes in salt concentration)
- Freezing
- Surface changes (occuring while beating egg whites)

Any of these factors may cause breaking of hydrogen bonds and salt bridges. As a result, the protein unfolds and side chains that were buried in the center of the molecule become exposed. They are then available to react with other chemical groups, and in most cases the denatured protein precipitates. This reaction usually is irreversible; it is not possible to regain the original conformation of the denatured protein.

The changes that produce denaturation usually are mild changes. In other words, mild heat treatment, such as pasteurization or blanching, or small changes in pH are sufficient to change the conformation of a protein.

Denatured proteins normally lose their functional properties; that is, they are unable to perform their normal function in a food. Enzymes are inactivated and so the reactions that they catalyzed no longer can take place. This has important implications in food processing.

Denaturation may be desirable and can be deliberately brought about by food processing. Examples of desirable denaturation include heating beaten egg white foams to form meringues, adding acid to milk to form cottage cheese, or inactivating enzymes by heat, as occurs when vegetables are blanched before freezing. Blanching is a mild heat treatment that denatures and inactivates enzymes that would cause rancidity or discoloration during frozen storage.

Sometimes denaturation is undesirable. For example, frozen egg yolks are lumpy and unacceptable when thawed because the lipoproteins denature and aggregate. Overheating of foods also can cause unwanted denaturation. Food processors must be careful to utilize processing methods that do not cause unnecessary deterioration of food quality due to protein denaturation.

Hydrolysis of Peptides and Proteins

Hydrolysis of proteins involves breaking peptide bonds to form smaller peptide chains. This can be achieved by acid digestion, using concentrated acid. This may be appropriate in protein research, but it is not an option in food processing. Hydrolysis also is catalyzed by ***proteolytic*** enzymes. Examples of such enzymes used in foods include ficin, papain, and bromelain, which are used as meat tenderizers. They hydrolyze muscle protein or connective tissue, making meat more tender. It is important to control the duration of time that they are in contact with the meat so that too much hydrolysis does not occur. Too much hydrolysis would make the texture of the meat soft and "mushy" (see Chapter 9).

Another example of a proteolytic enzyme is rennet, which is used to make cheese (see Chapter 11). This enzyme is very specific in its action, hydrolyzing a specific peptide bond in the milk protein. The result of this hydrolysis reaction is aggregation of the milk proteins to form curds, which then can be processed into cheese.

Maillard Browning

Maillard browning is the reaction that is responsible for the brown color of baked products. A free carbonyl group of a reducing sugar reacts with a free amino group on a protein when heated and the result is a brown color. The reaction is highly complex and has a significant effect on the flavor of foods as well as the color. It is known as nonenzymatic browning, because the reaction is not catalyzed by an enzyme (Maillard browning must be distinguished from enzymatic browning, which is the discoloration of damaged fruits or vegetables and is catalyzed by an enzyme such as phenol oxidase; enzymatic browning is discussed in Chapter 7).

The Maillard reaction is favored by the following:

- High sugar content
- High protein concentration
- High temperatures
- High pH
- Low water content

Maillard browning is responsible for the discoloration of food products such as powdered milk and powdered egg. Before drying, eggs usually are "desugared" enzymatically to remove glucose and prevent Maillard browning (see Chapter 10).

The reaction causes loss of the amino acids lysine, arginine, tryptophan, and histidine, as these are the amino acids with free amino groups that are able to react with reducing sugars. With the exception of arginine, these are essential amino acids. (The body cannot make them, and so they must be included in the diet.) Therefore, it is important to retard the Maillard reaction, particularly in susceptible food products (such as food supplies sent to underdeveloped countries) in which the nutritional quality of the protein is very important.

ENZYMES

All enzymes are proteins. Enzymes are important in foods, because they catalyze various reactions that affect color, flavor, or texture, and hence quality of foods. Some of these reactions may be desirable, whereas others are undesirable and produce unwanted discoloration or off-flavors in foods.

Each enzyme has a unique structure or conformation, which enables it to attach to its specific substrate and catalyze the reaction. When the reaction is complete, the enzyme is released to act as a catalyst again. All enzymes have an optimal temperature and pH range, within which the reaction will proceed most rapidly. Heat or changes in pH denature the enzymes, making it difficult or impossible for them to attach to their respective substrates, thus inactivating them.

If an enzymatic reaction is required in food processing, it is important to ensure that the optimal pH and temperature range for that enzyme is achieved. Outside the optimal range, the reaction will proceed more slowly, if at all. Heat treatment therefore must be avoided. If this is not possible, the enzyme must be added after heat treatment and subsequent cooling of the food.

On the other hand, if enzyme action is undesirable, the enzymes must be inactivated. This usually is achieved by heat treatment, but also may be accomplished by adding acid to change the pH.

Examples of desirable enzymatic reactions include the clotting of milk by *rennet*, which is the first step in making cheese (Chapter 11). Ripening of cheese during storage also is due to enzyme activity. Ripening of fruit also is due to enzyme action (Chapter 7). Other desirable enzymatic reactions include tenderizing of meat by proteolytic enzymes such as *papain*, *bromelain*, and *ficin* (Chapter 9). As was mentioned earlier, these enzymes catalyze hydrolysis of peptide bonds in proteins. They are added to the meat and allowed to work for a period of time. The reaction must be controlled to prevent too much breakdown of the proteins. The optimum temperature for these enzymes occurs during the early cooking stages. (Hydrolysis proceeds very slowly at refrigeration temperatures.) As meat is cooked, the enzymes promote hydrolysis. However, as the internal temperature continues to rise, the enzymes are inactivated and the reaction is stopped.

Although useful as meat tenderizers, proteolytic enzymes may be undesirable in other circumstances. For example, if a gelatin salad is made with raw pineapple, the jelly may not set, due to action of *bromelain*, which is contained in pineapple. This can be prevented by heating the pineapple to inactivate the enzyme before making the gelatin salad.

Other examples of unwanted enzymatic reactions include enzymatic browning, which occurs when fruits and vegetables are damaged, due to the action of *polyphenol oxidase*, and produces undesirable discoloration (Chapter 7). Development of off-flavors in fats and fat-containing foods also may be a problem in some circumstances, and this may be caused by *lipase* or *lipoxygenase* (Chapter 12).

Enzymes are inactivated in fruits and vegetables prior to freezing by a mild heat process known as blanching (Chapter 17). The fruits or vegetables are placed in boiling water for a short time, in order to inactivate the enzymes that would cause discoloration or development of off-flavors during frozen storage.

FUNCTIONAL ROLES OF PROTEINS IN FOODS

Proteins have many useful ***functional properties*** in foods. A functional property is a characteristic of the protein that enables it to perform a specific role or function in a food. For example, a protein with the ability to form a gel may be used in a food with the specific intention of forming a gel, as in use of gelatin to make jelly.

Functional properties or roles of proteins in foods include solubility and nutritional value. They also may be used as thickening, binding, or gelling agents and as emulsifiers or foaming agents.

The functional properties of a specific protein depend on its amino acid composition and sequence since these determine the conformation and properties of the protein. Although no single protein exhibits all the functional properties, most proteins may perform several different functions in foods, depending on the processing conditions. Some proteins are well known for specific functional properties in foods.

Whey protein is an example of a protein that is used for its *solubility* (Chapter 11). Whey is soluble at acid pH, because it is relatively hydrophilic and able to bind a lot of water, and so unlike many proteins it does not precipitate at its isoelectric point. Because of its solubility, whey protein is used to fortify acidic beverages such as sports drinks. Whey protein also may be used as a *nutritional fortifier* in other products including baked goods.

Egg proteins are used as *thickening* or *binding* agents in many food products (Chapter 10). Meat proteins also are good binding agents.

Gelatin and egg white proteins are examples of *gelling* agents (Chapter 10). When egg whites are heated, they form a firm gel as can be seen in a boiled egg. Gelatin is used to make jelly and other congealed products. Gelatin gels are formed when the protein molecules form a three-dimensional network due to association by hydrogen bonds. Gelatin gels can be melted by heating and reformed on cooling. Egg white gels, on the other hand, are formed due to association by hydrophobic interactions and disulfide bonds, and they do not melt on heating. The proteins of gluten are another example of proteins that are able to associate to form a three-dimensional network (Chapter 15). The gluten network is formed during kneading of bread dough and is responsible for the texture and volume of a loaf of bread. Soy protein also may be used to form food gels.

Many proteins are used as either *emulsifiers* or *foaming agents*, as discussed in Chapter 13. Proteins are ***amphiphilic***, containing both hydrophobic and hydrophilic sections in the same molecule. This allows them to exist at an interface between oil and water or between air and water, rather than in either bulk phase.

They are able to adsorb at an interface and associate to form a stable film, thus stabilizing emulsions or foams. Egg white proteins are the best foaming agents, whereas egg yolk proteins are the best emulsifying agents. The caseins of milk also are excellent emulsifiers.

Proteins are used in many foods to control texture, due to their ability to thicken, gel, or emulsify. Such food products must be processed, handled, and stored with care, to ensure that the proteins retain their functional properties. Some protein denaturation is usually necessary to form an emulsion, a foam, or a gel. However, too much denaturation due to incorrect processing conditions or poor handling and storage may result in undesirable textural changes (such as breaking of emulsions, loss of foam volume, or syneresis in gels) and must be avoided.

CONJUGATED PROTEINS

Conjugated proteins also are known as heteroproteins. They are proteins that contain a prosthetic group that may be an organic or an inorganic component. Examples of conjugated proteins include the following:

- Phosphoproteins—for example, casein (milk protein); phosphate groups are esterified to serine residues.
- Glycoproteins—for example, κ-casein; a carbohydrate or sugar is attached to the protein.
- Lipoproteins—for example, lipovitellin, in egg yolk; a lipid is attached to the protein.
- Hemoproteins—for example, hemoglobin and myoglobin; iron is complexed with the protein.

CONCLUSION

Proteins are complex molecules that are widely distributed in all foodstuffs. It is important to understand their conformation and reactions in order to know how they will behave during food processing and to understand how to maximize their functional properties. This is especially true of protein-rich foods, where the quality of the final product depends to a large extent on the treatment of the protein during processing and handling. This chapter has focused on general properties of food proteins. More details of the composition and functional properties of some specific food proteins are given in the ensuing chapters.

GLOSSARY

Amino acid: Building block of proteins; contains an amino group, a carboxyl group, a hydrogen, and a side chain, all attached to a central carbon atom.

Amphiphilic: A molecule that contains both hydrophobic and hydrophilic sections.

Amphoteric: Capable of functioning as either an acid or as a base depending on the pH of the medium.

Alpha helix: Ordered protein secondary structure: corkscrew shape, stabilized by intrachain hydrogen bonds.

Beta-pleated sheet: Ordered protein secondary structure; zigzag shape, stabilized by interchain hydrogen bonds.

Conformation: The specific folding and shape that a protein assumes in space.

Denaturation: Changes in the conformation (secondary, tertiary, or quaternary structure) of a protein caused by changes in temperature, pH or ionic strength, or by surface changes.

Dipeptide: Two amino acids joined by a peptide bond.

Disulfide bond: Strong covalent bond formed by the reaction of two thiol (SH) groups.

Functional property: Characteristic of the molecule that enables it to perform a specific role in a food. Examples of functional properties of proteins include solubility, thickening, binding, gelation, foaming, and emulsifying capacity.

Hydrolysis: Breaking of one or more peptide bonds in a protein to form smaller polypeptide chains.

Hydrophilic: Water-loving; characteristic of polar and charged groups.

Hydrophobic: Water-hating; characteristic of nonpolar groups.

Isoelectric point: pI; the pH at which the overall charge on a protein is zero; the number of positive charges is equal to the number of negative charges; the protein is most susceptible to denaturation and precipitation at this pH.

Maillard browning: The free carbonyl group of a reducing sugar and the free amino group of a protein react to form a brown color; complex nonenzymatic reaction that is favored by high temperatures.

Peptide bond: Bond formed by the reaction of the amino group of one amino acid and the carboxyl group of another.

Polypeptide: Several amino acids joined together by peptide bonds.

Protein primary structure: Specific sequence of amino acids along the protein chain, joined by peptide bonds, the covalently bonded protein backbone.

Protein quaternary structure: The noncovalent association of protein chains to form a discrete unit.

Protein secondary structure: Three-dimensional arrangement of sections of the protein chain; secondary structures include the α-helix, β-pleated sheet, and random coil.

Protein tertiary structure: Three-dimensional arrangement of the whole protein chain; the shape that a protein chain assumes in space; includes fibrous and globular structures.

Proteolytic: Breaks down or hydrolyses proteins.

Random coil: A protein secondary structure that exhibits no regular, ordered pattern.

Salting-in: Addition of a dilute salt solution to improve the dispersibility of a protein.

Salting-out: Addition of a concentrated salt solution to precipitate a protein.

Steric effects: Effects caused by the size and shape of the amino acids comprising the protein chain; spatial effects; for example, bulky amino acids can prevent a protein from folding upon itself in certain ways.

Water-binding capacity: The ability of a protein to bind water; this ability depends on the number of charged and polar groups along the protein chain.

Zwitterion: Contains a positively charged group and a negatively charged group within the molecule.

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CHAPTER 9

Meat, Poultry, Fish, and Dried Beans

INTRODUCTION

Meat is the edible portion of mammals—the flesh of animals used for food. “Meat” may include rabbit, venison, and other game, as well as the nonmammals poultry and fish. Various animal flesh may be used as food throughout the world.

Red meat is the meat from mammals including beef and veal, lamb, mutton, and pork. White meat refers to meat from poultry. Seafood is derived from fish and game is from nondomesticated animals. In addition to being sold fresh or frozen, meat also is available in processed or manufactured products.

Meat is composed of three major parts: muscle, connective tissue, and adipose tissue (fat). Lean meats contain less adipose tissue than well-marbled cuts of meat. The location of the cut of meat on the animal, muscle contraction, and postmortem changes all influence the degree of meat tenderness. Individual cuts vary in inherent tenderness, requiring different cooking methods

All meat is subject to mandatory *inspection* by the USDA and voluntary *grading*. After inspection, alteration may occur by processing methods including curing, smoking, restructuring, and tenderizing. Kosher and Halal inspections mean much more than having a religious official blessing.

Incomplete plant proteins of animal feed are resynthesized in meat and it is important to know that only animal protein is a *complete* protein. Thus, if meat consumption is minimized or omitted from the diet, for any number of reasons, an individual must obtain similar nutrients from a nonmeat source, such as combination of various plants (Chapter 7).

At the turn to this century, beef demand was on the upswing for the first time in two decades. Yet, some individuals may have environmental, religious, vegetarian, health, or other concerns related to the consumption of meat; thus, they might choose to avoid meat products or consume meat minimally. The USDA recommends to “go lean with protein” and to limit daily consumption to 5 ½ oz of meats, beans, eggs, or nuts.

Meat must satisfy the requirements of appearance, texture, and flavor, as well as nutrition, safety, and convenience. Therefore, if eating meat, it becomes important to know the effects of cooking meat on its various components.

CHARACTERISTICS OF MEAT

Physical Composition of Meat

Meat is composed of three tissues: muscle tissue, connective tissue, and adipose or fatty tissue. Each is discussed in the text below.

Muscle Tissue. Muscle tissue is referred to as the *lean* tissue of meat. It includes *cardiac, skeletal, and smooth muscle. Cardiac* muscle is located in the heart. *Skeletal* muscle, the primary component of the carcass, provides support for the weight of the body and movement, or locomotion. When a muscle is used, it serves to strengthen the bone to which it is attached (true in humans, too). *Smooth* muscle is the visceral muscle located, for example, in the digestive tract, reproduction system, and throughout the blood vessels of the circulatory system.

Inside the muscle cell membrane (Figure 9.1) there are ***myofibrils*** containing alternating thin and thick protein filaments, namely, the *actin* and *myosin*, which contract and relax in the living animal. They are varied in length, perhaps 1 or 2 inches long, and are very small in diameter. Each fiber is cylindrical with tapered ends and is covered by a thin connective tissue sheath called ***endomysium***. Small bundles of 20–40 fibers make up one primary bundle that represents the "***grain***" of meat. This primary bundle is surrounded by ***perimysium*** connective tissue.

CULINARY ALERT! In carving meats it often is recommended to cut "across the grain," thus shortening the fibers for enhanced tenderness.

Together, several primary bundles form a larger, *secondary* bundle that contains blood vessels and nerves. As is the case with the primary bundles that make it up, each secondary bundle also is surrounded by ***perimysium*** connective tissue. In turn, several of the secondary bundles are surrounded by ***epimysium*** connective tissue dividing one skeletal muscle from another. In *between* the muscle bundles, there are blood vessels (capillaries) and small pockets of fat cells.

Connective Tissue. This meat component is made up of protein and mucopolysaccharides. It is located throughout the muscle (Figure 9.1) and determines the degree of meat tenderness. Less is more tender. As mentioned, muscle bundles are surrounded with various types of connective tissue—endomysium, perimysium, and epimysium—structures that bind muscle fibers in bundles to form muscle. The connective tissue extends beyond the muscle fibers to form *tendons*, which attach the muscle to bones and hold and connect various parts of the body. Connective tissue also forms *ligaments*, attaching one bone to another. Additionally, the tough skin or hide of an animal is connected to underlying animal tissue by connective tissue.

It follows that meat containing a *high* degree of muscle tissue naturally has a *greater* amount of connective tissue to hold myofibrils and bundles in the muscle.

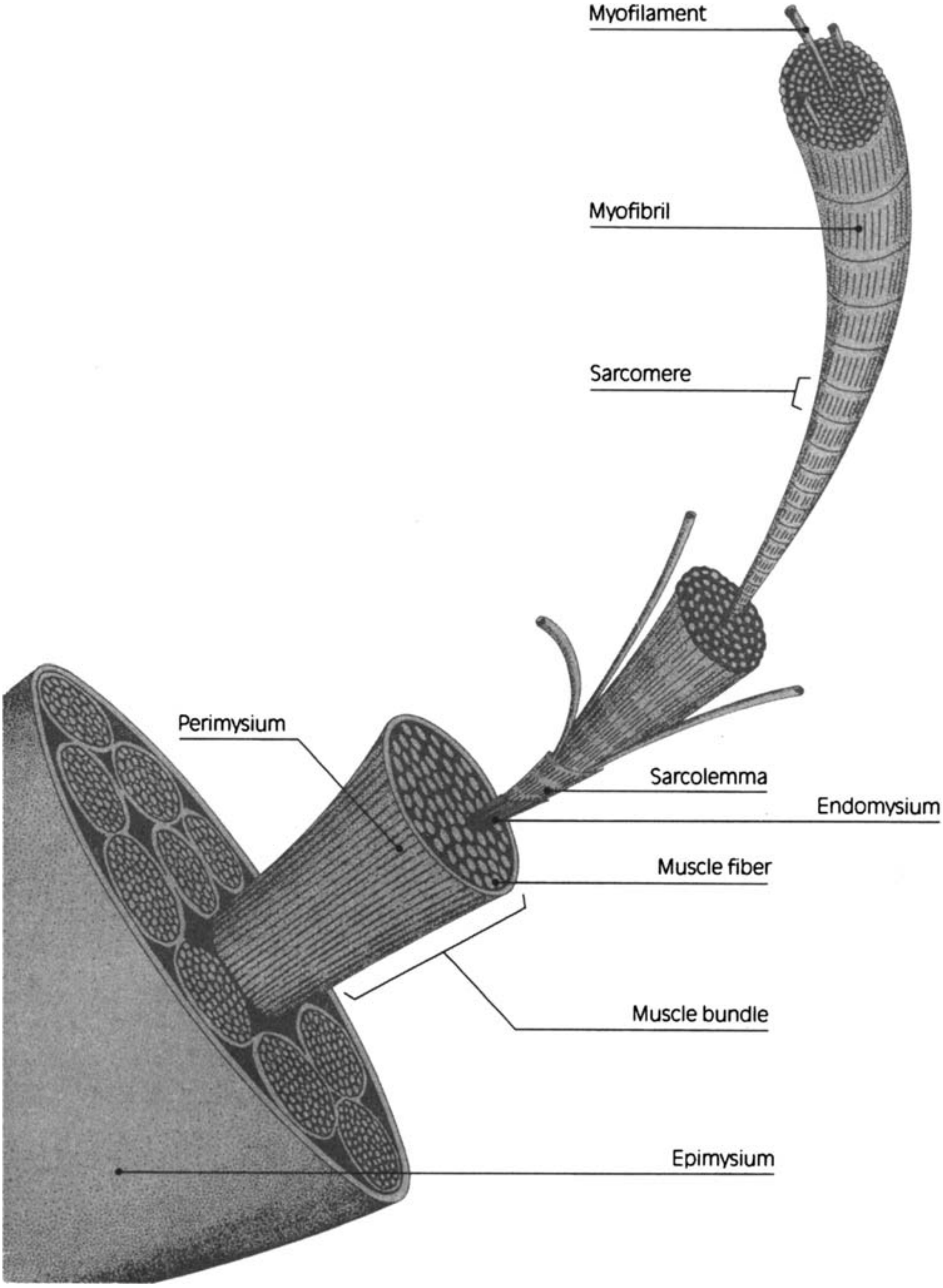


FIGURE 9.1 Diagram of a lean muscle and its connective tissue (*Source*: National Cattlemen's Beef Association).

Connective tissue is primarily protein held inside mucopolysaccharides. ***Collagen*** is the most abundant protein found in mammals—in bone, cartilage, tendons, and ligament, enveloping muscle groups, and separating muscle layers. It also is in horns, hooves, and skin.

Collagen is a triple-coil protein structure that is white in color and contracts to a thick mass when heated. Yet, it becomes tenderized when cooked with *moist* heat. This tenderization may be referred to in several manners. For example, collagen may be "*converted to*," "*solubilized to*," or "*gelatinized to*" water-soluble ***gelatin***. (This is the same gelatin that may in turn be used for edible gels in the diet.) In older animals, the collagen is increased and may form many cross-linkage, thus *preventing* solubilization of collagen to the more tender gelatin. The meat from older animals therefore is tough.

A *lesser* component of connective tissue is the yellow-colored ***elastin*** protein, which is more elastic than collagen. It is found in the flexible walls of the circulatory system and throughout the animal body, assisting in holding bone and cartilage together. Elastin is extensive in muscles used in locomotion, such as legs, neck, and shoulders. Unlike collagen, it is *not* softened in cooking.

Another minor connective tissue component is ***reticulin***. This is a protein found in *younger* animals. It may be the precursor of collagen or elastin.

Overall, connective tissue is present to a greater degree in the muscle of *older* animals. Meat high in connective tissue may be ground to break the connective tissue and increase tenderization of the meat.

Fatty Tissue. A third meat component is fat. Cuts of meat may vary substantially in composition and appearance due to the presence of ***adipose*** or ***fatty tissue***. Animal fat stores energy and its content is dependent on factors such as animal feed, hormone balance, age, and genetics. Fat is held by strands of connective tissue throughout the body and is deposited in several places such as around organs, under the skin, and between and within muscles as described below.

- **Adipose tissue**: fat that is stored around the heart, kidney organs, and in the pelvic canal areas. (*Suet* refers to the hard fatty tissue around the kidneys and other glandular organs of cattle and sheep.)
- **Subcutaneous fat** (finish): fat that is visible after the skin is removed. (This is also referred to as cover fat. If well trimmed, the visible fat layer is less apparent.)
- **Intermuscular fat**: fat between muscles (also known as seam fat).
- **Intramuscular fat**: fat within muscles (marbling) (Figure 9.2).

When cooked, the melted fat contributes to juiciness, the sensation of tenderness, and flavor. Thus, well-***marbled*** meat with intramuscular fat may be desirable (despite the high level of fatty tissues). *Lean* meat primarily is muscle tissue and is *lower* in fat. The percentage of fat stores in an animal generally will increase with the animal's age.

Chemical Composition of Meat

The *chemical* composition of meat varies to a large degree. Meat *may* contain 45–70% water, 15–20% protein, and anywhere from 5 to 40% fat, depending on the cut and trim. Meat contains no carbohydrate (except for the liver, which stores glycogen). These constituents are described in the following text.

Water

Water is the major constituent of meat and the *greatest percentage* is found in *lean* meat and young animals where *fatty tissue* is *low*. Then, as an animal becomes more mature and fatter, with more adipose tissue, the water forms a *smaller proportion* of the entire makeup compared to young, lean animals. Water

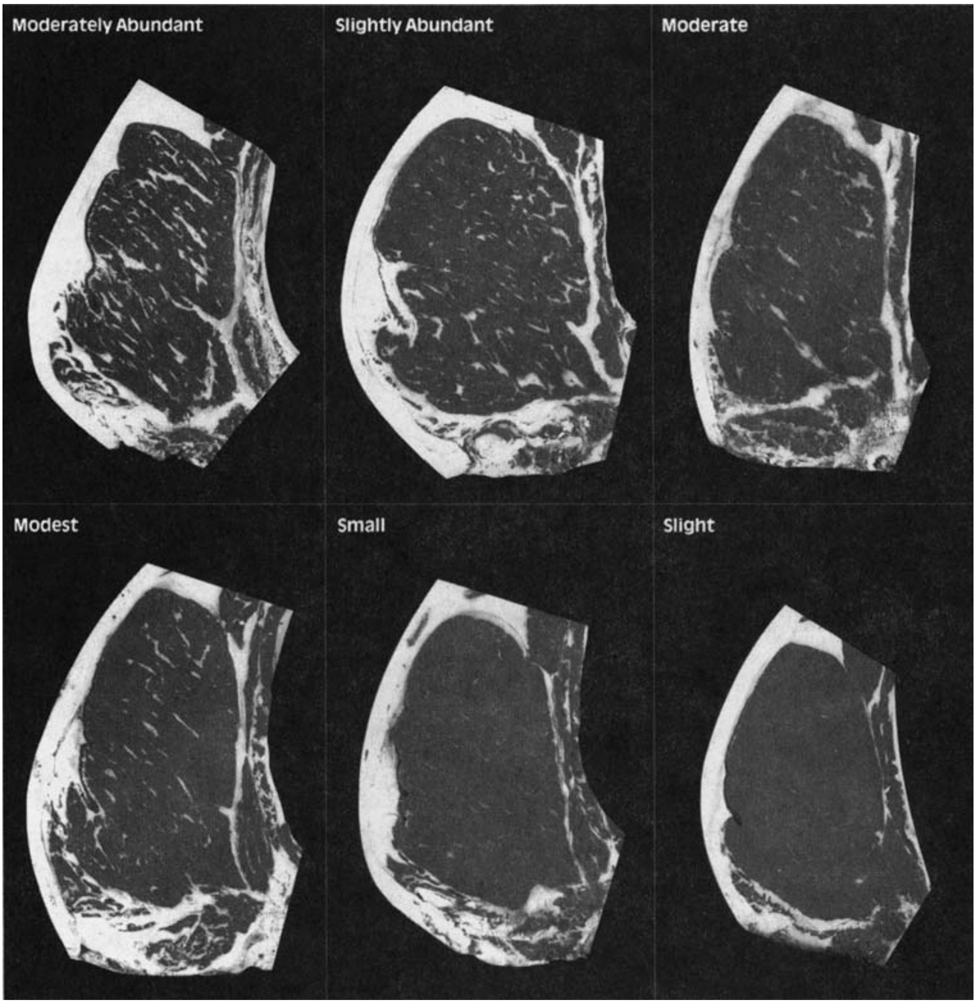


FIGURE 9.2 Different levels of fat marbling (*Source*: National Cattlemen's Beef Association).

exists in muscle fibers and to a lesser degree in connective tissue. It is *released* from the protein structure in a number of ways. For example, water loss occurs as the muscle coagulates during cooking, as muscle fibers are broken (due to chemical, enzymatic, or mechanical tenderization), by salting, and if the pH changes. Inversely, water may be *added* to meats such as cured ham.

CULINARY ALERT! A recent repercussion of labeling that meets the government's food safety requirements of raw meats and poultry is that an identification of water retention must be stated. Thus, according to the USDA, processors must list on food labels the maximum percentage of absorbed or retained water.

Protein

Meat is made of *high* biological value or *complete* proteins, containing all of the essential amino acids in amounts and proportions that can be used in synthesizing body proteins. The three primary types of proteins in meats are *myofibril, stromal proteins*, and *sarcoplasmic proteins* as described in the following:

- ***Myofibril proteins***: Muscle bundles are groups of *myofibrils* composed of several protein molecules including actin and myosin which may form an overlap complex called actomyosin.
- ***Stromal proteins (connective tissue proteins)***: The watery connective tissue contains fibrils of *stromal* proteins: collagen, elastin, and reticulin (discussed earlier).
- ***Sarcoplasmic proteins***: *Sarcoplasmic* proteins are a third general classification of meat proteins. They include the *pigments* and *enzymes*. For example, the hemoglobin *pigment* stores oxygen in the red blood cells bringing it to tissues, including the muscles, while myoglobin stores oxygen in the muscle where it is needed for metabolism.

Enzymes are proteins that may be *proteolytic* (degrading protein during the aging of meat), *amylolytic* (degrading carbohydrates), or *lypolytic* (degrading fats). There also are numerous enzymes in fluid of the muscle cell.

Fat

Fat may be a major component of meat, although veal contains only a small amount of fat. Fat varies in its degree of saturation (see Figure 9.2). For example, subcutaneous fats generally are more *unsaturated* than fat around glandular organs. *Saturated* fat promotes less oxidation, and therefore less rancidity. In the animal, fat contributes to the survival of the living animal at low environmental temperatures.

In the diet, fat allows the fat-soluble vitamins A, D, E, and K to be carried. As well, fats contain some essential fatty acids that are the precursor material used in the synthesis of phospholipids for every cell membrane.

Cholesterol, a sterol, is present in the cell membranes of all *animal* tissue. Typically, lean meats have a lower cholesterol content than higher-fat meats. An exception to this is veal (young, lean calf meat), which is *low* in fat, yet *high* in cholesterol.

Carbohydrates

Carbohydrates are plentiful in *plant* tissue but are negligible in *animal* tissue. Approximately half of the small percentage of carbohydrates in animals is stored in the *liver* as *glycogen*. The other half exists throughout the body as glucose, especially in muscles and in the blood. A small amount is found in other glands and organs of an animal. If an animal is exercised or not fed prior to slaughter, low stores of glycogen appear in the liver and muscles.

Vitamins and Minerals

Meat contains *water-soluble* B-complex vitamins that function as cofactors in many energy-yielding metabolic reactions. The liver stores *fat-soluble* vitamins A, D, E, and K. The minerals iron (in heme and myoglobin pigments), zinc, and phosphorus are present in meat.

MUSCLE CONTRACTION IN LIVE ANIMALS

Muscle tissue of slaughtered animals undergoes several changes *after* slaughter. In order to better understand the reactions that occur in meat and their effects on tenderness and quality, it is necessary to have a basic understanding of the structure and function of muscle in a live animal.

Structure of the Myofilaments of Muscle

As previously mentioned, muscle fibers contain bundles of myofibrils, which are responsible for contraction in the living animal. The myofibrils themselves are composed of bundles of protein filaments as shown in Figure 9.3. These include *thin* filaments, made mostly of actin, and *thick* filaments, which contain myosin. They are arranged in a specific pattern within a repeating longitudinal unit called a *sarcomere*.

The thin filaments occur at each end of the sarcomere and they are held in place by Z-lines. The Z-lines define the ends of each sarcomere. The thick filaments occur in the center of the sarcomere and they overlap the thin filaments. The *extent of overlap* depends on whether the muscle is contracted or relaxed. In a *relaxed* muscle, the sarcomeres are extended and there is *not* much overlap of thick and thin filaments. However, a *contracted* muscle has a *lot* of overlap because the sarcomeres shorten as part of the contraction process.

The thin and thick filaments are interspersed between each other in the regions where they overlap. A cross section of the myofibrils shows that each thick filament is surrounded by six of the thin filaments and every thin filament is surrounded by three of the thick filaments. This facilitates interaction between the thin and thick filaments when contraction occurs (see Postmortem Changes in the Muscle).

Muscle Contraction

Muscle contraction starts when a nerve impulse causes release of calcium ions from the sarcoplasmic reticulum into the sarcoplasm, which is a jellylike substance surrounding the thin and thick filaments of the myofibrils. The calcium ions bind to a specific site on the thin filaments, causing the active site on actin to be exposed. Actin molecules then are able to react with myosin, forming actomyosin. Adenosine triphosphate (ATP) is necessary as the energy source for this reaction. The myosin then contracts and pulls the actin-containing filaments further in toward the center of the sarcomere. The actomyosin complex then breaks and myosin forms another cross-link with a different actin molecule. As the cycle continues, the sarcomere continues to shorten due to the formation of more cross-links and contraction occurs.

When the nerve impulse ceases, calcium ions are pumped out of the sarcoplasm and returned to the sarcoplasmic reticulum. Actin and myosin cannot interact without calcium ions and so the actomyosin complex breaks. The muscle relaxes and returns to its original extended state.

Energy for Contraction

The energy for contraction comes primarily from aerobic respiration, which enables glucose to be broken down completely to yield CO_2 and 36 molecules of ATP. In animals, glucose is stored as glycogen, which is broken down as needed to supply energy. When short bursts of extreme muscle activity are necessary,

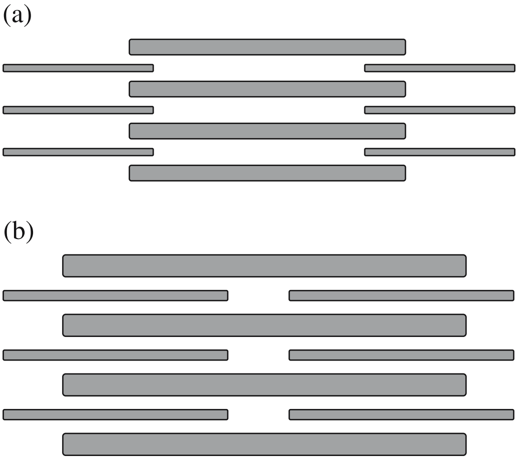


FIGURE 9.3 Sarcomere and protein filaments (a) relaxed (b) contracted.

aerobic respiration does not supply adequate amounts of ATP, and so energy is also obtained by anaerobic glycolysis. This is a more rapid but less efficient way of producing energy, as only two molecules of ATP are produced for every glucose molecule. Glycolysis converts glucose to lactic acid, which builds up in the muscle. (It is the build up of lactic acid that makes muscles sore and stiff after strenuous exertion. When the strenuous activity ceases, lactic acid is oxidized and removed from the muscle.)

Both aerobic respiration and glycolysis can take place in a *live* animal. *After* slaughter, aerobic respiration ceases, but glycolysis continues for a while.

POSTMORTEM CHANGES IN THE MUSCLE

Prior to slaughter, muscle tissue in the living animal is *soft and pliable*. Some time *after* slaughter (from 6 to 24 hours), muscle *stiffens* and becomes hard and inextensible. (Perhaps you have seen this in deer or other deceased animals in roadside accidents or hunting sites.) The time period for stiffening is species-specific and it is known as ***rigor mortis***, which literally means "the stiffness of death." This stiffening is due to loss of extensibility by the myofibril proteins, actin and myosin, once *energy reserves* become nonexistent and oxygen does not reach the cells.

If meat is cooked at this stage, it is extremely *tough*. In fact, most meat is *aged or conditioned* to allow the muscles to become *soft and pliable* again before it is cooked. This "*resolution of rigor*" is due to the enzymatic breakdown of proteins that hold muscle fibers together. This stiffness is temporary.

After slaughter, a sequence of events takes place in muscle that leads to the onset of rigor mortis. When the animal is killed, *aerobic* respiration ceases, blood flow stops, and the muscles are no longer supplied with oxygen. Therefore, *anaerobic* conditions soon prevail. Glycolysis continues and glycogen stores are converted to lactic acid with the formation of ATP. The reaction continues until glycogen stores are depleted or until a pH of 5.5 is reached. At this pH, the enzymes that are responsible for glycolysis are denatured and so the reaction *stops*. If glycogen is in short supply, glycolysis may stop due to depletion of glycogen before the pH drops as low as 5.5.

When glycolysis stops, the ATP supply is quickly depleted. Lack of ATP prevents calcium ions from being pumped out of the sarcoplasm, and so the active site on the actin molecules of the thin myofilaments is available to bind with the myosin of the thick filaments. Actin and myosin unite, forming *actomyosin cross-links*. This cross-link formation is irreversible, as there is no available ATP. (In a live animal, actomyosin cross-links are formed and broken repeatedly, as part of contraction, but the cycle requires ATP.)

Formation of these irreversible *actomyosin cross-links* causes the muscle to become rigid. This is *rigor mortis* and it correlates with the depletion of ATP in the muscle. Once formed, *actomyosin cross-links* do not break down, even during aging of meat, and their presence makes meat tough (Figure 9.3b).

Thus, the stiffness of the muscle at rigor depends on the extent of actomyosin formation, which in turn depends on the extent of *overlap* of the thin and thick myofilaments. Recall that the *greater* the overlap of thin and thick myofilaments, the more *extensive* the formation of actomyosin and the *stiffer* the muscle. This results in *tough* meat:

- Little overlap: few actomyosin cross-links (tender meat).
- Substantial overlap: many actomyosin cross-links (tough meat).

Because the extent of actomyosin formation affects the toughness of meat, it is important to *minimize* the number of *cross-links* formed. This is done in two ways:

1. The meat is *hung* on the carcass after slaughter to *stretch* the muscles. This minimizes shortening of the sarcomeres and results in formation of *fewer* actomyosin cross-links (more later).
2. *Prerigor temperature* is controlled to minimize fiber shortening. The optimum temperature is between 59°F and 68°F(15–20°C). *Above* this temperature, increased shortening occurs. *Below* it, "cold shortening" occurs. At low temperatures, the sarcoplasmic reticulum pump is unable to pump calcium ions out of the sarcoplasm and so contraction occurs (more later).

Both hanging the carcass and controlling prerigor temperature minimize contraction before the onset of rigor mortis, resulting in fewer actomyosin cross-links and increasing tenderness.

Ultimate pH

After slaughter, the pH drops due to the buildup of lactic acid, which normally is removed from the blood of the living animal. The *ultimate pH* is the pH that is reached when glycolysis ceases and usually is around 5.5. As mentioned already, glycolytic enzymes are close to their isoelectric point and are inactivated at this pH, thus preventing glycolysis from continuing. Therefore, a pH of 5.5 is the lowest possible ultimate pH. It is possible to obtain a higher ultimate pH if the animal is starved or stressed before slaughter. This depletes the glycogen reserves; thus glycolysis stops before sufficient lactic acid has been formed to bring the pH to 5.5. Meat with a high ultimate pH has excellent water-holding capacity, because many of the proteins are not as close to their isoelectric point, and therefore are able to bind more water. However, a low ultimate pH is desirable from a microbiological point of view because it inhibits microbial growth. A high ultimate pH results in poor resistance to microbial growth.

The *rate of change* of pH after slaughter also has a significant effect on the quality of meat. A *rapid* pH change while the temperature is still high causes considerable denaturation of contractile and/or sarcoplasmic proteins and loss of water-holding capacity. Lysozomal enzymes also are released at high temperatures, and these cause hydrolysis of proteins. Such *undesirable* changes may happen if the carcass is *not* cooled rapidly after slaughter [eg, if the pH drops to 6.0 before the temperature of the carcass drops below 95°F(35°C)].

Aging or Conditioning of Meat

Natural aging or conditioning of meat involves holding meat for several days, beyond rigor mortis. Under controlled storage conditions of temperature and humidity (and perhaps light), the muscles become soft and pliable again, making the meat tender. Meat aging occurs as muscles become tender due to (protein and) actomyosin breakdown. A protease, which is active at around pH 5.5, breaks down the thin myofilaments at the Z-lines. This causes the muscle to become pliable again and meat to be tender. The sarcoplasmic proteins denature and there is some denaturation of the myofibril proteins, with a resultant loss of water-holding capacity; and so the meat drips. Collagen and elastin do not denature significantly during aging.

CULINARY ALERT! Natural, proteolytic enzymes in meat may sufficiently tenderize meat in the time between slaughter and retail sale; however, controlled aging is sometimes induced.

As mentioned above, actomyosin formation affects the toughness of meat and it is important to minimize the number of cross-links formed. This is done in two ways. Aging is achieved by *hanging* the carcass in a cold room, at 34–38° F(2 °C), for 1–4 weeks. Although the meat regains tenderness after about a week, the best flavor and tenderness develop in about 2–4 weeks. Humidity levels of approximately 70% are controlled and the meat may be wrapped in vacuum bags to minimize dehydration and weight loss.

Higher temperatures for shorter times, such as 68° F(20° C) for 48 hours, also have been used to age beef. However, development of surface bacterial slime tends to be a problem for meat aged by such methods. It is shown that exposing the meat to ultraviolet light during the aging is of help in this regard.

Aging methods differ among meat types. For example, pork and lamb do *not* require aging such as occurs with beef, as the animals are slaughtered while they are young and inherently tender. They usually are processed the day following slaughter.

MEAT PIGMENTS AND COLOR CHANGES

Meat tissue may appear as red meat or white meat, depending on the predominant pigment and its concentration contained in the meat. The two major pigments in meat responsible for the red color are myoglobin and hemoglobin. *Myoglobin* (with one heme group as part of its structure) is 80–90% of the total meat pigment (see Chemical Composition of Meat). It allows oxygen to be stored in the muscles. *Hemoglobin* (with four heme groups in its structure) is present at levels of 10–20% of well-bled meat. It carries oxygen in the bloodstrtream.

Myoglobin, the primary pigment contributor of meat, is purplish-red. It is present in frequently exercised portions of the animal that expend great amounts of oxygen, such as muscles of a chicken leg. It produces the “dark meat “ of turkey, for example. The specific myoglobin level is influenced by the species, age, sex, and specific muscle. There is *more* myoglobin in the muscles of cows than pigs, *more* in older sheep than young lambs, and *more* in bulls (adult males) than cows.

When *myoglobin* is exposed to oxygen in the air, bright red, oxygenated *oxymyoglobin* is produced. With time, *metmyoglobin* is apparent. It is the *undesirable*, brownish-red colored pigment found in meat due to oxidation of the iron molecule. Metmyoglobin is found in several situations: in meat that is *not* fresh, which contains significant levels of bacteria, is exposed to light, or is exposed to low levels of oxygen (Figure 9.4). In summary, changes in pigment may result from exposure to oxygen, acidity, and light.

In processed meats, such as lunchmeats, nitrites may be added in order to both preserve the desirable pink color and control the growth of *Clostridium botulinum*.

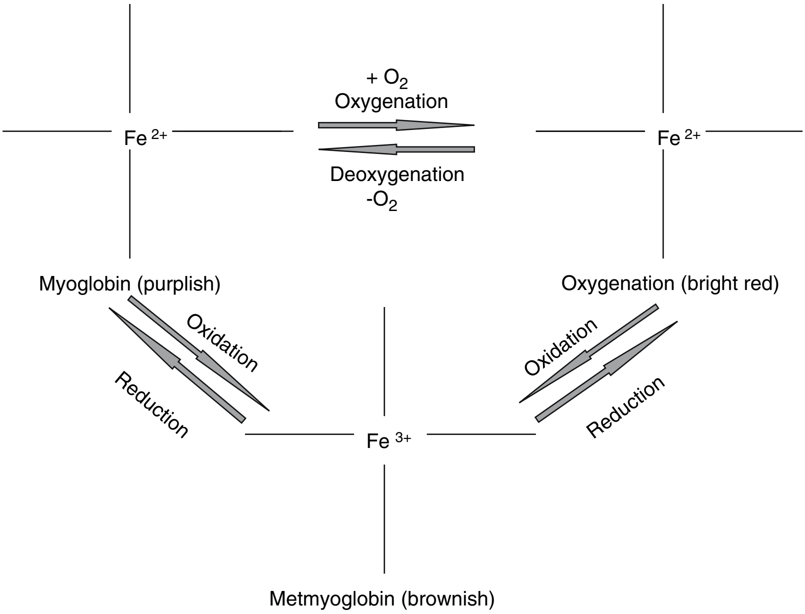


FIGURE 9.4 Pigment change.

FIGURE 9.5 The USDA inspection, quality grade and yield grade stamps (*Source*: USDA).

MEAT-HANDLING PROCESS

USDA Inspections

"United States Inspected and Passed" and the packaging/processing plant number is specified in the round *stamp* (Figure 9.5) found on the primal cut of inspected meat. The stamp is made of a nontoxic purple vegetable dye. Packaged *processed* meat must show a somewhat *similar stamp* on the packaging or *carton* of the meat. It is common for specific *state* inspection stamps (as opposed to USDA) to display a stamp with the shape of the state. Inspections for *wholesomeness* and accurate *labeling* are a service of the US government and are paid for with tax dollars.

The *Federal* Meat Inspection Act of 1906 requires inspection of all meat packing plants slaughtering and processing meat for *inter*state commerce. The Wholesome (Wholesale) Meat Act of 1967 required the same inspection program for *intra*state transport.

Trained veterinarians and agents of the USDA Food Safety and Inspection Service (FSIS) inspect the *health* of the animal, as well as *the sanitation* of the plant. The inspection for meat is *mandatory* (Chapter 20). Meat's inspection for *wholesomeness* indicates that it is safe to eat, without adulteration, and that examination of the carcass and viscera of the animal did *not* indicate the presence of *disease*. (It is *not* meant to imply freedom from all disease-causing microorganisms.)

Inspections occur *before*, *after*, and *throughout* meat processing. Diseased and unwholesome animals may *not* be used; harmful ingredients may *not* be added; misleading names or labels may *not* be used, and there must be established sanitation codes for the plant. Safety in meat processing is of utmost importance to the processor and customer alike. Violations of the Meat Act are fined and persons committing violations have been imprisoned. The Meat Inspection Program also controls and monitors *imported* meat.

Since the pathogenic microorganism *Escherichia coli* 0157:H7 may be undetected *only if visual inspections* are used for inspection, *bacterial counts* were included in inspections. In 1997, inspections included the *Hazard Analysis and Critical Control Point* (HACCP) method of food safety (Chapter 16). It is the current program for inspecting meat with the inclusion of bacterial count checks.

A regulatory watch is in regard to meat from cloned animals and their offspring. The FDA's Risk Assessment underwent a peer review and utilized independent scientific experts. To date, they have found that meat from cloned animals is as safe to eat as food from animals that are conventionally bred.

Kosher Inspection

Kosher inspection indicates that the meat is "*fit and proper*" for consumption or is "*properly prepared.*" Following Mosaic and Talmudic Laws, a specially trained rabbi slaughters the animal, eg, beef, lamb, goat, and the meat is well bled and then salted. All processing is done under the supervision of individuals authorized by the Jewish faith. According to Mosaic Law, meat *must* come from an animal that does not have split hooves and chews its cud. Therefore, hogs and all pork products *cannot* be Kosher.

The Kosher stamp (Figure 9.6) does not indicate grade or wholesomeness. Meat is *still* subject to federal or state inspection.

Overall, there are more that 46,000 Kosher-certified products available on the market. The Kosher market comprises only 20% of Jewish people. Muslims and other religious groups comprise 30% of the Kosher market. The lactose-intolerant and vegetarian consumers make up 25%; 25% are health conscious consumers (1). Of course, not all persons of Jewish faith keep Kosher in their diet.

It may appear that Kosher is considered an acceptable substitute for proper and permitted Muslim foods; however, this is *not* the case. Only *some* foods are acceptable as discussed in the upcoming text is Halal certification for Muslim requirements.

Halal Certification

The Halal certification indicates "*proper and permitted.*" Only foods prepared and processed under Halal standards are to be consumed by Muslims, although not all persons of the Muslim faith keep to a diet of solely Halal certified foods.

Certification uses trained Muslim inspectors who assist, participate in, and supervise food production in companies complying with Halal standards.

FIGURE 9.6 Kosher symbol
(*Source*: National Cattlemen's Beef Association).

FIGURE 9.7 Halal certification
(*Source*: Islamic Food and Nutrition Council of America).

A *crescent M* symbol on the product package indicates that the product meets the Halal standards of the Islamic Food and Nutrition Council of America.

The types of foods permitted, including use of additives, slaughtering, packaging, labeling, shipping, and other aspects of food handling, are *regulated*. For example, the Halal production does *not* accept alcohol, gelatin prepared from swine (for use as a food ingredient or packaging ingredient), or meat from animals that were *not* individually blessed.

Halal does not employ the same processing as Kosher food, although some products bear certification that they *are both* Kosher and Halal. As per the founder and president of a company producing both Kosher and Halal refrigeration-free meals, "For a product to be Kosher or Halal means much more than having the product blessed by a religious official" (1) (Figure 9.7).

In conclusion, there exist 13–14 million persons of the Jewish faith and 1 billion Muslims in the world. Their dietary laws are *not* interchangeable, but are *similar*. A look at dietary restrictions of other religions is included in another reference (3). As is true for Kosher, the Halal certification does not indicate grade or wholesomeness. Meat is *still* subject to federal or state inspection.

GRADING OF MEAT

Voluntary grading is part of the processing cost and is *not* paid for by tax dollars. The task of *grading* of meat (as opposed to the inspection of carcasses) was established by the USDA in 1927. It reports on both *quality* and *yield*, as described below (Figure 9.5).

Voluntary *quality* grading evaluates various characteristics of animals. Evaluation includes age; color of lean; external fat quality and distribution; marbling; shape of animal carcass; and firmness of the muscle and meat texture (coarseness of muscle fiber bundles). So it looks at an evaluation of marbling, maturity, texture, and appearance.

Beef grades are according to the grades listed below. *Other* meats have *different* standards with fewer categories of grades:

- Prime
- Choice
- Select
- Standard
- Commercial
- Utility
- Cutter
- Canner

Prime grades of beef are very *well* marbled. Prime is followed by choice, select, and standard rankings with *less* marbling. The younger animal is more likely to be tender and receive a grade of prime, choice, select, or standard.

Older, more mature aged beef typically qualify for commercial, utility, cutter, or canner grades.

In addition to voluntary *quality* grading, meat is also graded for *yield*, which is useful at the wholesale level. The highest percentage of lean, boneless yield (usable meat) on the carcass is given an assigned yield grade of "1." If yield of a carcass is *less*, the yield grade may be assigned a value as low as "5." Sales and marketing of meat products are based on grades and yields.

HORMONES AND ANTIBIOTICS

Hormone and antibiotic use are both monitored by the FDA. *Hormones* may be used in animal feeds to promote growth and/or to increase lean tissue growth and reduce fat content. All hormone use in animal feeding must be *discontinued* for a specified time period prior to slaughter and must be *approved* by the FDA. A random sampling of carcasses provides tests for and monitors growth hormone residues (growth promotants).

Antibiotics in animal feeds also are a food safety concern. Antibiotics have been used for well over 50 years to treat disease, and the FDA monitors their use in animal feeds to prevent their transfer to humans. *Subtherapeutic* doses of antibiotics do more than treat *already-existing* diseases; such doses may be used to *prevent* disease and promote growth of animals. With this practice, the *therapeutic* administration of antibiotics to humans may be rendered ineffective if antibiotic-resistant strains of bacteria are passed from the livestock to humans. A 1989 study by the National Academy of Sciences (NAS) concluded that they were "unable to find data directly implicating the subtherapeutic use of feed antibiotics in human illness."

Although danger to human health has not been shown, the FDA (even recently) has urged that specific antibiotics used to treat animals be removed from the market, if they have been found to compromise other drugs used in treating animals or humans. "There are many countries [such as Denmark] that do not allow antibiotics as growth promoters in farm animals" (6).

Antibiotics that are used *solely* for the purpose of *animal* growth often is debated. Unfortunately, as has been reported in the press involving *human* growth hormone, a small percentage of illegal users may stay just one step ahead of regulatory inspectors.

CUTS OF MEAT

Primal or Wholesale Cuts

A *primal* cut is also known as a *wholesale* cut of an animal. Meat cutting separates cuts into *tender* and *less tender* cuts and *lean* and *fatty*. Cuts differ with species and primal cuts of *beef* are identified below. They are listed according to tenderness. *Less exercised* skeletal muscles that provide support (cuts of meat along the backbone, such as the loin) are usually tenderer than other skeletal muscles that are used in *locomotion*. Ultimately, though, tenderness is a function of how meat is torn by the teeth, not just the cut, age, and so forth.

Most Tender	Medium Tender	Least Tender
Rib	Chuck	Flank (< brisket)
Short loin	Round	Short plate
Sirloin		Brisket
		Foreshank
		Tip

Subprimal Cuts

Subprimal cuts are divisions of *primal* cuts, often sent to the grocery market for further cutting. They may be boneless. If they are vacuum packed, they are considered to be "beef-in-a-bag," or if boxed, "boxed meat." Subprimal cuts are further divided into individual *retail* cuts such as roasts, steaks, and chops.

Retail Cuts

Retail cuts are those available in the *retail* market, cut from primal or subprimal cuts. They may be named for the primal cut in which they are located *or* for the bones they contain (Figure 9.8).

In general, cuts from the neck, legs, and lower belly are *least tender* because as mentioned they are the most exercised portions of the animal. They are made more palatable when cooked with *moist heat* to soften connective tissue, although the same less tender cuts may be cooked with *long*, dry heat cooking at low temperatures and produce a satisfactory product. *Tender* cuts are cooked with *dry heat*.

CULINARY ALERT!

- Less tender cuts: moist heat or long, low heat cooking
- Tender cuts: dry heat cooking, quick

The wholesale and retail cuts of beef are identified in Figure 9.8. In the1970s, the National Livestock and Meat Board [now National Cattlemen's Beef Association (NCBA)] coordinated a committee of retail and meat industry representatives and federal agencies, which standardized names for 314 retail cuts of meat. They published the *Uniform Retail Meat Identity Standards* (URMIS). URMIS labels include the kind of meat (beef, veal, pork, or lamb), the primal cut from which

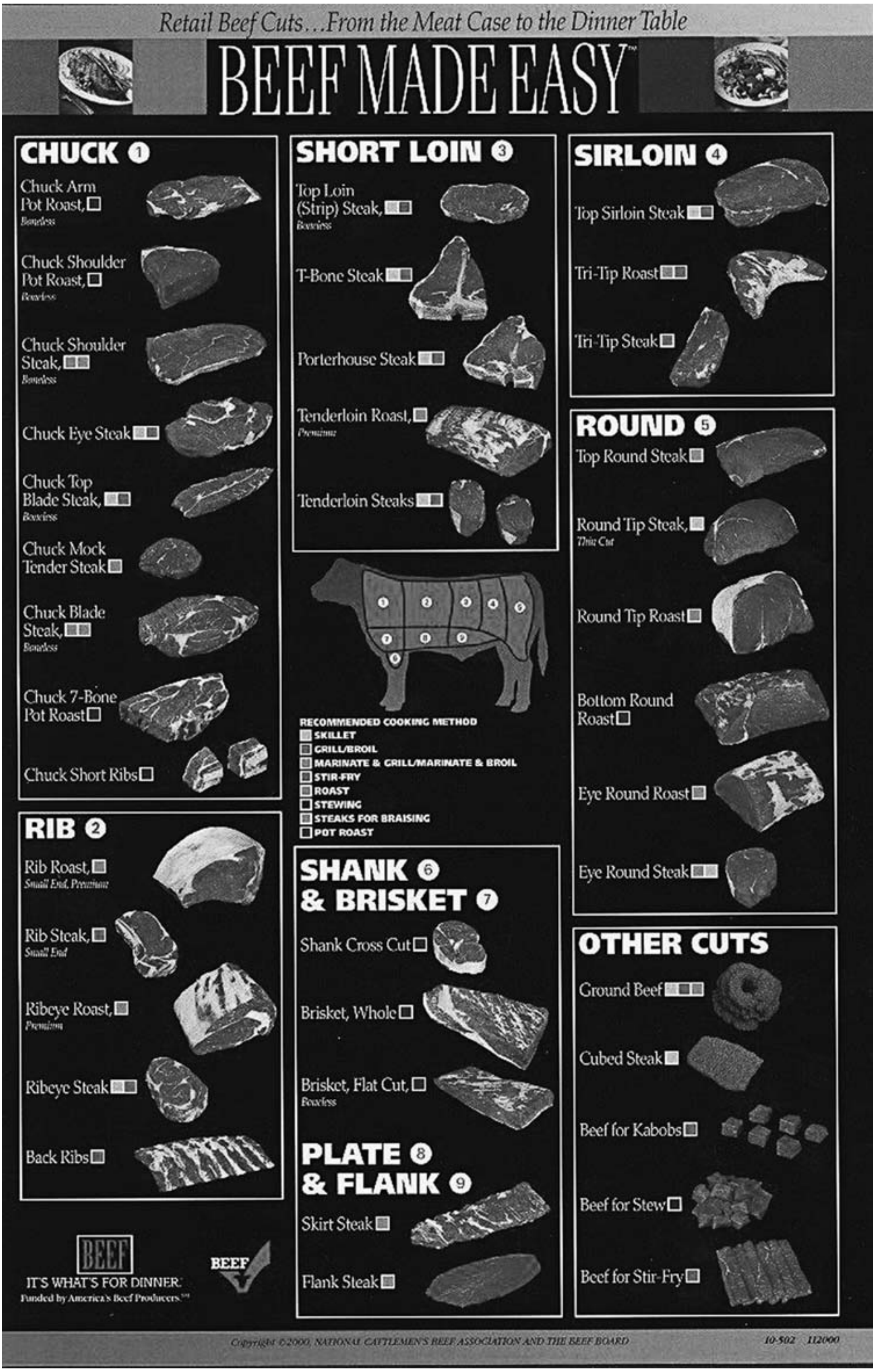


FIGURE 9.8 Wholesale and retail cuts of beef. (*Source*: USDA).

the meat originated (chuck, rib, loin, or round of the animal), and the name of the retail cut.

- **Beef** (Figure 9.8) is *most commonly* obtained from carcasses of the following:
    - Steer: young castrated male carcass
    - Heifers: young females before breeding, beyond veal and calf age
- **Beef** is *less frequently* obtained from the carcasses of the following:
    - Cows: females that have had a calf
    - Bulls: adult male
    - Baby beef: young cattle, 8–12 months of age
    - Calves: young cattle, 3–8 months of age, beyond veal classification
- **Vea**l is from the carcass of:
    - Beef calves, generally 3 weeks to 3 months or more
    - Veal is milk-fed, not grass-fed, thus is low in iron and pale in color
    - Young calf meat is normally lighter pin-gray than older calf meat
- **Pork** is the flesh of swine (pig)
- **Lamb** is the flesh of *young* sheep, not more than 14 months old
- **Mutton** is the flesh of sheep *older* than 2 years

COOKING MEAT

The processing plant and consumer both require a familiarity with types of cuts and cooking methods for meat. Although it may be a lot to ask, meat must satisfy the requirements of appearance, texture, and flavor, as well as nutrition, safety and convenience. To better assure success, it is critical to know the effects of cooking meat on its various components.

At the turn to this century, beef demand was on the upswing for the first time in two decades (7). Of course, some individuals may have environmental, religious, vegetarian, health, or other concerns related to the consumption of meat; thus they might choose to *avoid* meat products or to consume meat minimally.

CULINARY ALERT! The purpose of cooking is to improve appearance, tenderness, and flavor while destroying pathogenic microorganisms.

In cooking, the peptide chains of amino acid chains uncoil (denature) and reunite or coagulate, releasing water and melted fat (Chapter 8). Consequently, the meat shrinks. When heat is applied, muscle fibers toughen and connective tissue becomes tender. These reactions are opposing effects and the method, time, and temperature of cooking differ.

Effects of Cooking on Muscle Proteins

Muscles used in locomotion (muscles for physical movement) and muscles of older animals contain a greater number of myofibrils in each muscle. Thus muscle bundles are physically larger and the large size indicates that they have a more coarse grain.

Temperatures around 131° F(55°C) precipitate myosin and 158–176°F (70–80°C) precipitates actin. This denatures, shortens, toughens, and shrinks the surrounding connective tissue, causing a loss of water-holding capacity. The longer the cooking time, the more serious this effect will be, although at temperature of 170°F (77°C) tenderness may improve.

Tender cuts of meat contain *small* amounts of connective tissue and should be cooked for a short time at a *high* temperature with dry heat. Such cooking minimizes coagulation and shrinkage of muscle fibers and prevents loss of water-holding capacity. Toughening of the muscle fibers is minimized if tender cuts are cooked to *rare* rather than the well-done stage.

Tender meat that is *overcooked* tends to be *dry and tough* because the protein coagulates, water is squeezed out, and myofibrils toughen. Greater cooking intensity for a short time is advantageous for tender cuts of meat and prolonged cooking is recommended for *less tender* cuts of meat.

Effects of Cooking on Collagen

When collagen, the major component of connective tissue, is heated, hydrogen bonds and some heat-sensitive cross-links are broken. At temperatures between 122°F and 160°F (50–71°C) connective tissue begins shrinking. Some of the tough-structured collagen is then solubilized and converted to gelatin. As the collagen fibers are weakened, the meat becomes tenderer. Breakdown (or "melting," solubilization, gelatinization) of collagen is faster as collagen reaches higher temperatures.

Young animals contain few cross-links in collagen, thus, it is readily converted to gelatin and meat tends to be tender. Collagen from *older* animals, on the other hand, contains many more covalent cross-links, most of which are *not* broken down by cooking; therefore, older animals yield tough meat unless it is heated in a *moist* atmosphere.

Cuts of meat *low* in collagen, such as rib or loin steaks, are inherently tender and do *not* benefit from slow, moist heat cooking. These cuts are tenderer when cooked *quickly* and served to the *rare* or *medium-rare* stage.

On the other end of the spectrum, when collagen levels in a cut of meat are *high*, slow, moist heat cooking, to achieve a *well-done* stage, is recommended as it gelatinizes the collagen. Some tenderization of the meat surface (1/4 inch) occurs as meats are placed in marinades.

Effect of Cooking on Fat

Fat melts throughout the meat with cooking, and therefore produces a perception of a tender product. If a cut is high in fat content or well marbled, it yields a more tender cooked meat. In left-over meat, fat oxidation contributes to flavor deterioration.

Methods of Cooking

Generally, as mentioned previously, there are various "best" methods of cooking: dry heat and moist heat.

- **Dry heat methods** of cooking include broiling, frying, pan-frying, roasting, sautéing, and stir-frying. Meat is cooked *uncovered. Tender* steaks, chops, ground meat, and thin cuts are cooked this way.
- **Moist heat methods** of cooking include braising, pressure-cooking, simmering, steaming, stewing, or using a slow-cooking pot to simmer. Meat is cooked *covered. Less tender* cuts such as chuck, flank, or round may be cooked in this manner.

Meat contains water, and therefore to some extent *all* meat, if it is covered, provides moist heat cooking. This reduces surface drying that occurs with dry heat cooking and gives time for collagen to become gelatin.

The effect of *dry* heat (uncovered) and *moist* heat (covered) on two *identical*, less tender cuts of meat such as the chuck or round is reported. When both roasts are removed from the oven at the *same* time, the *covered* roast temperature shows a lower temperature and less weight loss. Covering is preferable for these less tender cuts.

Other Factors Significant in Cooking

Cooking *methods* have previously been discussed. However, additional factors are significant in cooking. For example, pigments, the reading of thermometers, searing, and removal temperature are important factors in cooking. They are discussed in the following:

- **Pigments**. Color may be an indication of the degree of doneness. When cooked, the myoglobin pigment is denatured, and therefore meat changes color from a red or purple to pale gray-brown.
- **Use of thermometers**. The use of a calibrated thermometer to measure temperature provides the necessary assurance that the recommended cooking temperature is achieved. The cooking thermometer may be designed to detect

multiple food temperatures along its stem and show an "average" temperature of those multiple readings. Depending on where/how the thermometer is inserted (into the fat, muscle, or placement near a bone), temperature is influenced.

CULINARY ALERT! The thermometer will give a false reading, and therefore should *not* be placed in the fat or near a bone. Thermometers provide a more accurate reading of meat doneness when they are inserted at an angle rather than vertically where fat could drip down the stem and again give a false reading.

- **Searing**. Initial high heat, or the practice of "searing" with *dry* heat imparts flavor; however, further *moist* heat cooking is used for the continued cooking of less tender cuts of meat, high in collagen-containing connective tissue.
- **Removal temperature**. Large roasts increase in internal temperature for 15–45 minutes or more *after* removal from the oven. Roasts removed from the oven at the *rare* stage (more moisture) exhibit a *greater* temperature rise following removal from the oven than roasts removed at the drier, *well-done* stage. This should be kept in mind when a specific doneness is desired.

Specific temperatures for doneness of meat are as follows:

Doneness	Temperature
Rare	140°F (60°C)
Medium-rare	150°F (65°C)
Medium	160°F (71°C)
Well done	170°F (77°C)

CULINARY ALERT! Roasts increase in temperature following removal from the oven. Use a calibrated thermometer correctly.

ALTERATIONS TO MEAT

Processed Meat

Processed meat is defined as meat that has been changed by any mechanical, chemical, or enzymatic treatment, altering the taste, appearance, and often keeping the quality of the product. It may be cured, smoked, or cooked and it includes cold cuts (lunch meats), sausage, ham, and bacon. Processed meats may be available in low-fat formulations.

Of all the meat produced in the United States, about 34% is processed. Approximately 75% of processed meat is *pork* and 25% is *beef* and a small amount is *lamb or mutton*. Meat that has been processed is subject to the same USDA inspection as other meat. If formulated with meat trimmings and variety meats, that must be stated on the label.

Processed meats may contain salt, phosphates, nitrate (NO_3), or nitrite, which provide beneficial *microbial control*. Additionally, these ingredients supply flavor, texture, and protein-binding contributions (see Restructured Meats) to foods. Processed meats may contain a reduction or replacement of sodium. Sectors of the population watching sodium or some additives may desire to reduce their intake of processed meat.

The FSIS allows specific additions to meat. *Carrageenan* and locust bean gum may be used. *Xanthan* gum at maximum levels of 0.5% to prevent escape of the brine solution added to cured pork products is allowed. *Nitrite* is added to processed meat to preserve the color of meat and control the growth of *C. botulinum*.

A health concern regarding the addition of *nitrites* is that they could combine with amines (the by-product of protein breakdown) in the stomach and form carcinogenic "nitrosamines." This was addressed in a December 1981 report by the NAS that stated that neither sodium nitrate nor nitrite was carcinogenic. Nitrites remain at levels less than 50 ppm in processed meat at the point of consumption. Many processors add ascorbic acid (vitamin C), erythorbic acid and their salts, sodium ascorbate, and sodium erythorbate to cured meat to maintain processed meat color. These same additives also inhibit the production of nitrosamines from nitrites.

Curing and Smoking of Meat

Curing is a modification of meat that increases shelf life, forms a pink color, and produces a salty flavor. As mentioned, cured meats contain nitrite which controls the growth of *C. botulinum*. Additional color changes to the cured meat may result in fading as the pigment *oxidizes* when exposed to oxygen. Exposure to *fluorescent light* actually may give cured hams a fluorescent sheen and also causes a graying or fading of the color. Therefore, cured meats are packaged so that they are *minimally* exposed to the deleterious effects of oxygen and light.

Ham (pork) and corned (cured) beef as well as bacon and pastrami are very popular *cured* meats. Corned beef was given the name because beef was preserved with "corns" (grains) of salt.

Smoked meats prepared on a smoker are very popular in parts of the United States; they are relatively unheard of in other localities. Commercially or at home, beef, ham, and turkey are smoked (heat processed) to impart flavor. Liquid smoke also can be used to impart flavor.

CULINARY ALERT! Smoking treats meat by exposure to aromatic smoke of hardwood and also dehydrates, thus offering microbial control to the meat.

FDA Ruling on Smoking and Curing

http://www.cfsan.fda.gov/~dms/fcannex6.html

Introduction

Meat and poultry are cured by the addition of salt alone or in combination with one or more ingredients such as sodium nitrite, sugar, curing accelerators, and spices. These are used for partial preservation, flavoring, color enhancement, tenderizing, and improving yield of meat. The process may include dry curing, immersion curing, direct addition, or injection of the curing ingredients. Curing mixtures typically are composed of salt (sodium chloride), sodium nitrite, and seasonings. The preparation of curing mixtures must be carefully controlled. It is important to use curing methods that achieve uniform distribution of the curing mixture in the meat or poultry product.

FDA Definitions

Cured meat and poultry can be divided into three basic categories: (1) uncomminuted smoked products; (2) sausages; and (3) uncomminuted unsmoked processed meats.

(1) *Uncomminuted smoked products* include bacon, beef jerky, hams, pork shoulders, turkey breasts, turkey drumsticks.

(2) *Sausages* include both finely ground and coarsely ground products. Finely ground sausages include bologna, frankfurters, luncheon meats and loaves, sandwich spreads, and viennas. Coarsely ground sausages include chorizos, kielbasa, pepperoni, salami, and summer sausages.

(3) *Cured sausages* may be categorized as (1) raw, cured; (2) cooked, smoked; (3) cooked, unsmoked; and (4) dry, semidry, or fermented.

(4) *Uncomminuted, unsmoked processed products* include corned beef, pastrami, pig's feet, and corned tongues. This category of products may be sold either as raw ready-to-cook or ready-to-eat.

FDA Incorporation of Cure Ingredients

Regardless of preparation method, cure ingredients must be distributed throughout the product. Cure ingredients may be introduced into sausage products during mixing or comminution. Proper and thorough mixing is necessary whether the cure is added to the formulation in dry or solution form. Muscle cuts may be cured by immersion into a curing (pickle) solution. These methods are slow to diffuse curing agents through the product. Products must be properly refrigerated during immersion curing.

Several methods may be used to shorten curing times. These include hot immersion curing greater than 49°C (> 120°F), injection by arterial pumping (eg, hams), and stitch pumping by a series of hollow needles. If the injection method is used, injection needles must be monitored frequently during processing to ensure that they are not fouled or plugged.

Tumbling or massaging also may be used as an aid to hasten curing. Proper sanitation must be observed to prevent contamination during this operation.

The dry curing method, a similar process, also may be used. In this case, curing ingredients are rubbed over cuts and surfaces of meat held under refrigeration. Precautions must include wearing sanitary gloves when meat is handled. Product temperature maintenance is critical.

FDA Smoking

Smoking is the process of exposing meat products to wood smoke. Depending on the method, some products may be cooked and smoked simultaneously, smoked and dried without cooking, or cooked without smoking. Smoke may be produced by burning wood chips or using an approved liquid smoke preparation. Liquid smoke preparations also may be substituted for smoke by addition directly onto the product during formulation in lieu of using a smokehouse or another type of smoking vessel. As with curing operations, a standard operating procedure must be established to prevent contamination during the smoking process.

Restructured Meat

Restructured meat contains muscle tissue, connective tissue, and adipose tissue of a natural cut of meat; however, proportions of each may differ. In the process of restructuring, meat is (1) flaked, ground, or chunked to a small particle size, (2) reformed, and (3) shaped, perhaps into roasts or steaks.

Myosin in the meat muscle may be instrumental in causing meat particles to bind together. As well, salts, phosphates, and other *nonmeat* binders such as egg albumen, gelatin, milk protein, wheat, or textured vegetable protein may be added for the purpose of holding protein particles together. Generally, the restructuring process provides a less expensive menu item that *resembles* a whole meat portion. It offers consistency in serving size and appearance. Most boneless hams and some breakfast meats are restructured meats.

Artificial Tenderizing

Tenderizing meats may be desirable prior to cooking. *Young* animals are *naturally* tender and do not need *artificial* tenderizing. Recall that the connective tissue of *older* animals contains more covalent cross-links, is less soluble, and less readily converted to gelatin. Therefore, meat from older animals may require tenderization. In addition to the age, the origin of the cut on the animal also is a factor influencing tenderness.

The less tender cuts of meat may be *artificially* tenderized to break down the proteins of muscle or connective tissue. This may be achieved by mechanical, electrical, or enzymatic treatment as discussed below.

The *mechanical* tenderization includes chopping, cubing, and grinding. Meat may cubed, ground, or pounded prior to stuffing or rolling or used in a recipe. These techniques break the surface muscle fibers and connective tissue. A special instrument that pierces the meat with multiple thin, tenderizing needles is involved in the "needling" or "blade tenderizing" of meat.

Electrical stimulation such as ultrasonic vibration indirectly tenderizes meat by the physical vibrations that stimulate muscles to breakdown ATP to lactic acid. It also decreases the pH. The electrical stimulation of a carcass tenderizes without degrading the muscle fibers and texture of meats to a mushy state.

Natural *enzyme* tenderizers derived from tropical plants are available as powders or seasoning compounds that may be applied by dipping or spraying meat. They are more effective in tenderizing than marinades, which only penetrate approximately one-fourth inch into the interior of the meat. Enzymes include papain from the papaya plant, bromelain from pineapple, and ficin from figs.

Some of these enzymes treat the muscle tissue and others treat the connective tissue. For example, the enzymes chymopapain, or papain, and ficin exert a greater effect on tenderizing *muscle fibers* than *connective tissue*, while bromelain degrades *connective tissue* more than the myofibrils. Any overapplication of natural enzyme tenderizers to meat surfaces or allowing the treated meat to remain at temperatures conducive to enzymatic activity could produce an *overly* soft meat consistency.

The natural enzyme tenderizer papain also may be injected into the jugular vein (bloodstream) of an animal a few minutes before slaughter. It is distributed throughout the animal tissue. The enzyme is heat activated [by cooking at 140–160° F(60–71° C)] and eventually denatured in cooking.

CULINARY ALERT! With the addition of acid marinades to meat, collagen is softened to gelatin. The collagen fibers exhibit swelling and retain more water. Tomato and vinegar are acids that cause meat to respond in this manner and become tender.

There is a more *recent* development utilized in tenderizing meat without affecting appearance and taste. A *noninvasive process* used to tenderize meat employs a three-minute cycle in a high pressure, water-filled, closed tank. A 4-foot diameter stainless steel tank sealed with a stainless steel domed lid creates a high-pressure wave as a small explosive charge is detonated within the *tank*. Lower grades of meat, especially cuts that are low in fat content, may increase in value as they are made more tender for consumer use (8).

POULTRY

Poultry (bird) sales increased in times when beef sales declined. All poultry is subject to *inspection* under the Wholesome Poultry Products Act of 1968 and is *graded* US grade A, B, or C quality based on factors including conformation, fat, and freedom from blemishes and broken bones. The inspection, labeling, and handling of poultry products is similar to the meat inspection process (Chapter 19).

Chicken is the *primary* poultry consumed in the US diet. It is classified according to age and condition of the bird as follows:

• Broilers/fryers	2–2.5 lbs, 3–5 months of age
• Roasters	3–5 lbs, 9–12 weeks of age
• Capons	4–8 lbs, less than 8 months of age
• Hens, stewing hens, or fowls	2.5–5 lbs, less than 1 year
• Rock Cornish game hen	1–2 lbs, 5–7 weeks of age

Turkey is the *second* most frequently consumed poultry in the United States and is classified as follows:

• Fryers/roasters	10 weeks of age
• Mature roasting birds	20–26 weeks of age
• Tom turkey (male)	greater than 5 months of age

Duck, geese, guinea, and pigeon provide variety to the diet but are consumed less frequently than chicken or turkey. Each is subject to inspection by the USDA's Food Safety and Inspection Service (FSIS).

The *dark meat* of poultry represents portions of meat from more exercised parts of the animal. It contains *more* myoglobin, fat, and iron and zinc than *white meat*. Dark meat contains *less* protein. However, regarding fat content, any poultry *without* skin on during cooking allows less drippage of fat into meat than poultry cooked with the skin. It is possible that poultry *with* skin may contain slightly more of the lipid cholesterol than an equal portion of lean beef.

In addition to the whole bird, individual pieces of breast meat, legs, or thighs are sold separately and there are many *processed* poultry products on the American market. For example, many *lunch meats* contain turkey or chicken which provide the benefit of poultry in place of beef or pork, which may reduce fat content. *Ground turkey* may serve as a replacement for *ground beef* in cooked dishes and many formed entrees such as nuggets, patties, or rolls are available to the consumer.

Poultry carries *Salmonella* bacteria and must be adequately cooked to assure destruction of this pathogen (Chapter 16). The FSIS allows the use of trisodium phosphate as an antimicrobial agent on raw, chilled poultry carcasses that have passed for wholesomeness.

FISH

In addition to mammals and birds, fish is consumed by many people. *Fish* is both edible finfish and shellfish (see below) obtained from marine and freshwater sources. The edible fish represents the flesh from the skeletal muscles. Fish is *softer* and *flakier* than either mammals or poultry, because muscle fibers exist as short bundles, which contain thin layers of connective tissue.

Worldwide, there are several thousand species of seafood, and with current processing, preservation, and marketing methods, a greater variety of species are consumed. Yet, only a few species are used as edible fish and shellfish (Figure 9.9). Fish are classified as follows.

1. **Finfish** (vertebrate with fins): Finfish are fleshy fish with a bony skeleton and are covered with scales. They may be lean or fat. For example:
   - Lean saltwater fish: cod, flounder, haddock, halibut, red snapper, whiting.
   - Lean freshwater fish: brook trout and yellow pike.
   - Fat saltwater fish: herring, mackerel, and salmon.
   - Fat freshwater fish: catfish, lake trout, and whitefish.

FIGURE 9.9 Fish (Courtesy of SYSCO® Incorporated)

2. **Shellfish** (invertebrates): Shellfish are either crustaceans or mollusks; the former with a crustlike shell and segmented bodies, the latter with soft structures in a partial or whole, hard shell. Some examples are as follows:
   - Crustacea: crab, crayfish, lobster, and shrimp.
   - Mollusks: abalone, clams, mussels, oysters, and scallops.

The physical components of fish are similar to mammals; for example,

- Carbohydrate: neglible content
- Fat: variable percentage, primarily liquid (hence, fish *oil*) and *not* saturated.

  [fish feed on marine and freshwater *plants* that contribute to their high content of omega-3 polyunsaturated fatty acids. Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) both demonstrated to be protective against diseases, such as heart disease.]

- Protein: high quality, complete proteins including:
  - myofibril proteins—actin and myosin;
  - connective tissue—collagen; and sarcoplasmic proteins—enzymes and myoglobin.

In times past, the "R-Month Rule" stated that the months of September through April indicated safe harvesting of shellfish. The letter "R" is in their spelling, and these are also colder months. Today, adequate refrigeration and care dispels this belief.

Fish is classified as inherently tender because fish contains *less* connective tissue than beef and *more* of it converts to gelatin during cooking. The *flakes* that appear in a cooked fish are due to a change in connective tissue that occurs with heating and are a sign that cooking is complete.

CULINARY ALERT! The appearance of flakes in cooked fish indicate doneness.

Restructured or "formed" fish of various types that have been minced prior to cooking will *not* show such flakes. *Minced fish* may be produced from less popular varieties of fish or from the fish-flesh remains of the filet process.

The washed, minced fish, coupled with heating, produces gel-like properties in the flesh and it may be "*formed*" for use as various products. For example, with centuries of production in Japan and developing technology in handling, the minced fish is used in the production of fish sticks, nuggets, patties, or other unbreaded, "formed" fish items.

In the production of *surimi*, for example, minced fish such as pollack is washed to remove both oil and water-soluble substances such as colors and flavor compounds, leaving only protein fibers as the remains. The washing also removes sarcoplasmic proteins that interfere with the necessary gelling (thus some oil and sarcoplasmic enzyme residue remaining in the fibers).

After washing, the flesh (protein fibers) is mixed with salt to solubilize the myofibril proteins, actin and myosin. Other characteristic flavors and pigments, as well as ingredients that promote the elastic texture and stability of the product, are added to the fish so that it may be incorporated into chowders, resembles crabmeat, lobster meat, or sausage-type products

If surimi (itself from Pollack) is used to create these products, they are called "imitation" (eg, "imitation crabmeat"). Two of the more common raw fish dishes are sashimi and sushi. Sashimi is sliced and prepared fish and sushi if vinegared rice, rolled with raw fish, and covered with seaweed. Care in handling is required of raw fish dishes.

In addition to meat, poultry, and fish, other protein sources in the diet are listed below.

DRIED BEANS AND PEAS (LEGUMES)

Legumes offer great variety in the diet. As plant material, legumes are *incomplete* proteins, while *complete* proteins are animal proteins that contain all the essential amino acids present at superior levels, for example, meat, poultry, fish, or milk and eggs.

In order to obtain the same essential amino acid profile as complete proteins, two or more *plant* protein foods are typically *combined*. For example, a vegetarian diet frequently may combine legumes (beans or peas) with either nuts, seed, or grains.

Legumes, for example, soybean, black-eyed peas, pinto beans; good source of lysine; poor source of (limited) tryptophan and sulfur-containing (S–C) amino acids (soybeans contain tryptophan).

Nuts and seeds, for example, peanuts, sesame seeds; good source of tryptophan and S–C amino acids; poor source of lysine (peanuts contain less S–C amino acids).

Cereals and grains (whole grains) corn, rice, whole grains (Chapter 4); good source of tryptophan and S–C amino acids; poor source of lysine (corn is a poor source of tryptophan and good source of S–C amino acids; wheat germ is poor in tryptophan and S–C amino acids but a good source of lysine).

Mutual supplementation is the name given to this combination of two or more complementary sources of incomplete proteins. The requirement is that they are combined in a *day* (not needed in the same *meal*) in order to provide the *essential amino acids*. Examples seen in the chart include combining beans and rice, tofu and vegetables on rice, black-eyed peas served with cornbread, tofu and cashews stir-fry, or chickpeas and sesame seeds (hummus) or peanut butter on whole wheat bread.

CULINARY ALERT! Combine the appropriate incomplete proteins in order to create a complete protein.

Legumes

Legumes (Figure 9.10) are the seeds of a pod of the *Leguminosae* family. The seed, found inside the pod, splits into two distinct parts attached to each other at the lower edge. They include edible peas that may be green, yellow, white, or

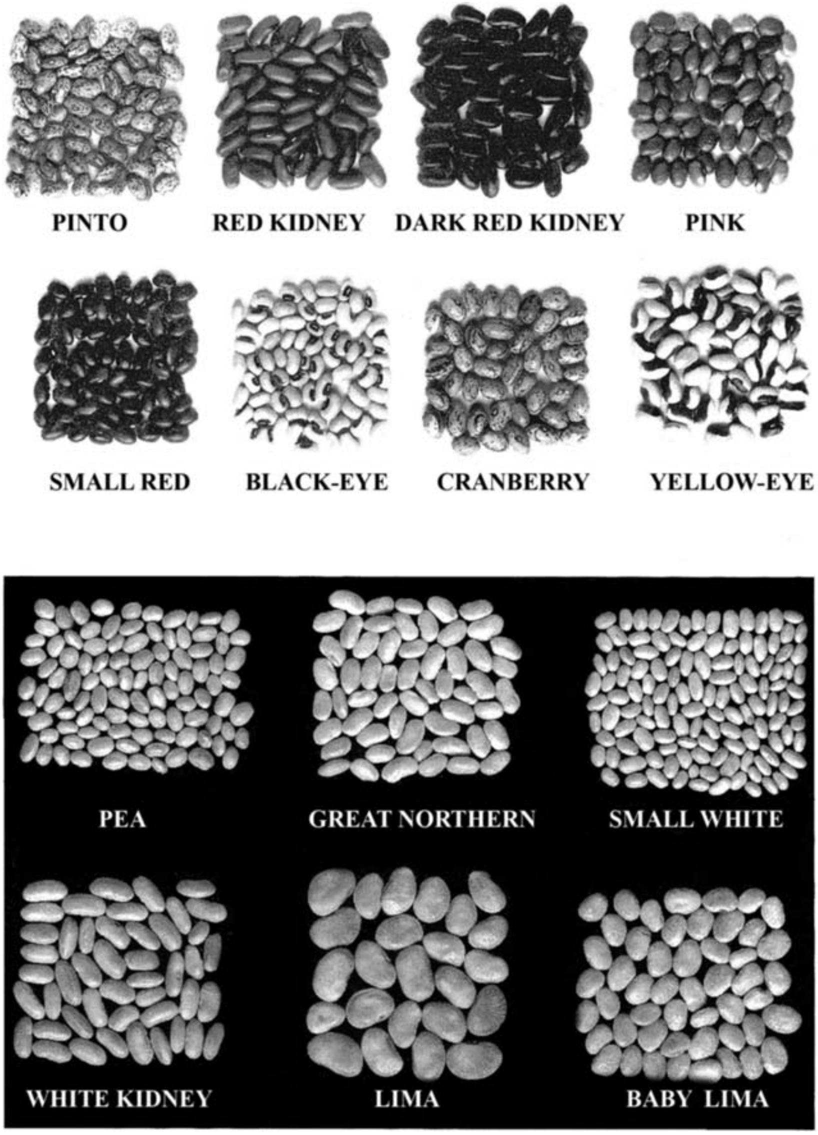


FIGURE 9.10 Examples of some common legumes (*Source*: USDA).

variegated in color. They include sugar peas with edible pods, black-eyed peas, and more.

Legumes may be elongated, flattened, spherical, or kidney-shaped. Notable are kidney beans, soybeans, or the edible, podded string beans/snap bean or green bean. Some beans, such as mung beans, are sprouted for culinary use. Alfalfa and clover may be used for animal fodder. Often, legumes may be referred to as a pulse and part of the bean or pea family.

In addition to beans and peas, carob pods, and lentils are legumes. Peanuts, despite their name, are *not* true nuts, but rather legumes. They are the high-protein seeds of a brown pod that appears contracted between the seeds (humped and inverted). Their ripening occurs underground.

Noticeable changes occur in cooking legumes such as softening due to gelatinization of starch and flavor improvement. The protein is coagulated and its availability is higher following cooking.

Legumes may cause intestinal distress and gas in some consumers. Therefore, an enzyme derived from *niger* has been processed for addition to foods such as these and is available to consumers for their dietary use.

CULINARY ALERT! Beans and peas [along with cruciferous (cabbage family) vegetables and whole grains in the diet] are wholesome food choices recommended by physicians and dietitians for healthy eating. They are low in fat, contain no cholesterol, and are good sources of fiber.

Typically, soybeans are derived from an autumn harvest and are processed into oil, tofu, frozen dessert, "flour," or textured vegetable protein:

- **Soybean oil**, pressed from the bean, is the highest volume vegetable oil in the United States and is commonly a constituent of margarine.
- **Tofu** is soy milk that has been coagulated to make the gel. Tofu is available in various types, ranging from soft to extra firm, depending on the water content. Extra firm tofu may be cut into small pieces and used in stir-fry cooking.
- **Frozen dessert**: the curd is further processed and sweetened; it may be served as a frozen tofu-based dessert, similar to ice cream or ice milk. The soft tofu may be an ingredient of "shakes" or frozen, sweetened dessert mixtures.
- **Soy flour** is made of dehulled beans with the oil (that was 18%) pressed out. It is used by consumers who cannot consume wheat or flours with gluten-forming proteins. It is nongluten. Although a soybean is not a cereal, it may be a source of "flour" in recipes.
- **Textured vegetable protein (TVP)** is used by food-service establishments, including school lunch programs, that use soy protein on their menus. TVP may simulate a ground form of meat or meat flakes; it resembles the texture of meat and is a good source of protein in meatless diets. It is the

principal ingredient in artificial bacon sprinkles used for salads and other foods. In combination with colors, flavors, and egg binders (for ease of fabrication), the often-unpleasant characteristic flavor of soybeans can be covered.

- **Fermented soybeans** produce soy sauce, miso, and tempeh. Soy sauce is a combination of the fermented soy and wheat. Miso is fermented soybean and/or rice used in oriental sauces and soup bases. Tempeh is similar to tofu but is inoculated with different bacteria.
  - A soy protein *concentrate* is soy that has been defatted, with soluble carbohydrate removed. It is *70%* protein. An even higher quality soy ingredient may be manufactured using a soy protein isolate.
  - An *isolate* is *90%* protein, with even more of the nonprotein material extracted; with the addition of flavors and colors, it may be satisfactorily included in numerous foods. Nuts are addressed in the discussion of fruits and vegetables (Chapter 7).

MEAT ALTERNATIVES

Quorn (pronounced "kworn") is a meat alternative that became available to American consumers in January 2002 after being sold in Europe for over a decade. It is a fungus made into many meat-type products including patties, nuggets, and casseroles. A former FDA food safety Chief (Sanford Miller, PhD), senior fellow at the Center for Food and Nutrition Policy, states that "This product meets what the nutrition community thinks a product should be and in addition, it tastes good! Modern science can fabricate anything. (FDA) We can imitate anything, but we always run into problems on how to have it taste good. Not taste alright, but taste good. This product does that."

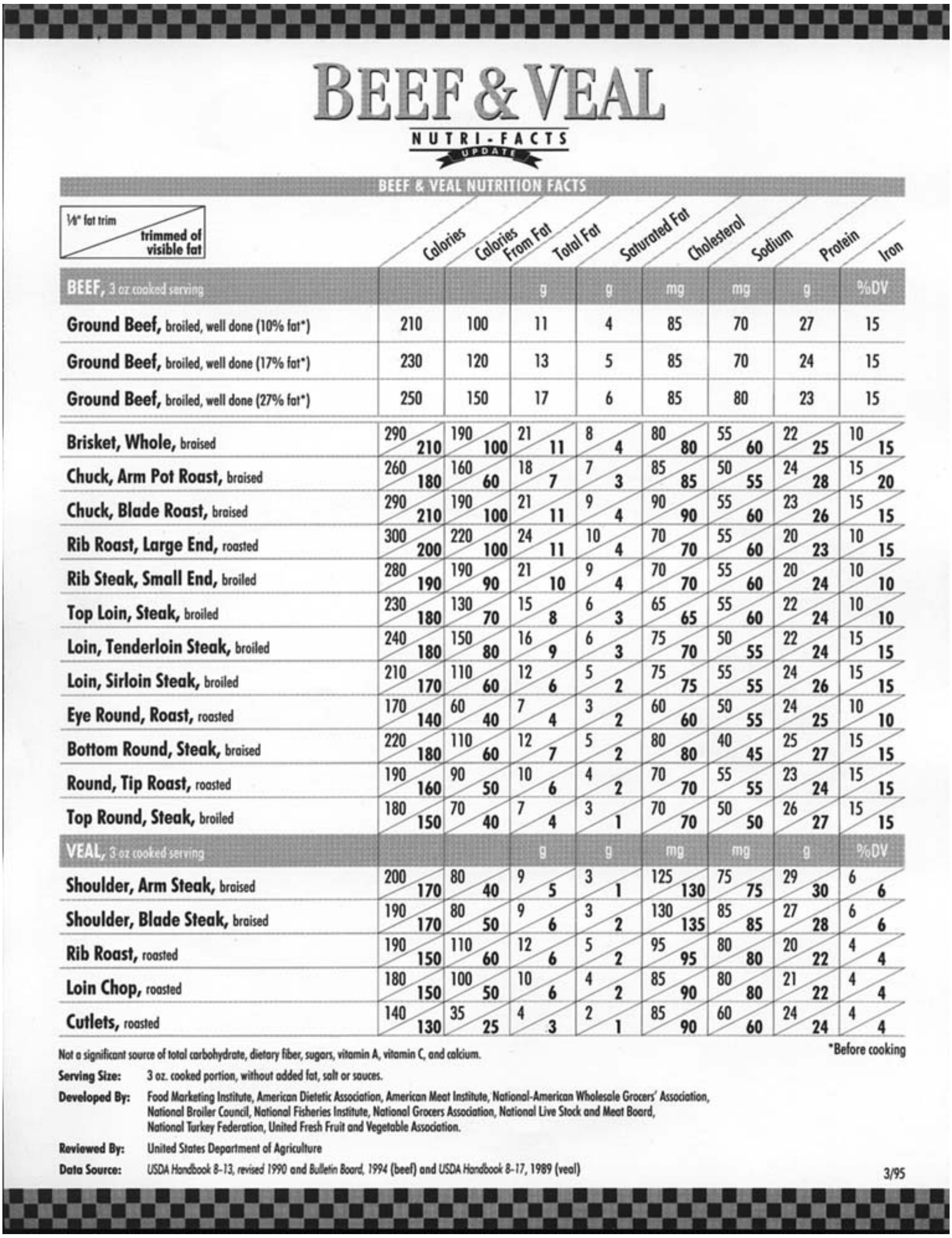
The mycoprotein was approved after undergoing a 5-year approval process with extensive animal and human testing. This process included a close look at possible allergens, which showed less than the allergens of mushrooms or soy (9).

According to an earlier report by the Center for Science in the Public Interest (CSPI) claims on some labels that the key ingredient in quorn is "mushroom in origin" were not true. "Quorn products contain no mushrooms. Rather, the so-called 'mycoprotein' in these products is actually grown in large fermentation vats from *Fusarium venenatum,* a nonmushroom fungus. On other quorn packages, the source of mycoprotein is omitted altogether . . . Consumers aren't surprised to find mushrooms or vegetables in a meat substitute."

CSPI Executive Director Michael F. Jacobson said, "But quorn's mycoprotein has nothing to do with mushrooms, plants, or vegetables. It is a fungus and should be labelled as such. Saying that quorn's fungus is in the mushroom family is like saying that jellyfish are in the human family." If an obscure term like "mycoprotein" is to be used in quorn's ingredient listings, says CSPI, packages should be required to disclose clearly the product's fungal origins."

NUTRITIVE VALUE OF MEAT, POULTRY, AND FISH

Some nutritive value aspects of meats (beef, veal, pork, and lamb), poultry (chicken and turkey), and fish and shellfish are shown in Figures 9.11–9.14. These Nutrifacts figures are the most recent ones reviewed by the USDA (USDA).



BEEF & VEAL

NUTRI-FACTS

UPDATE

BEEF & VEAL NUTRITION FACTS

1/8" fat trim / trimmed of visible fat	Calories	Calories From Fat	Total Fat	Saturated Fat	Cholesterol	Sodium	Protein	Iron
BEEF, 3 oz cooked serving			g	g	mg	mg	g	%DV
Ground Beef, broiled, well done (10% fat*)	210	100	11	4	85	70	27	15
Ground Beef, broiled, well done (17% fat*)	230	120	13	5	85	70	24	15
Ground Beef, broiled, well done (27% fat*)	250	150	17	6	85	80	23	15
Brisket, Whole, braised	290 210	190 100	21 11	8 4	80 80	55 60	22 25	10 15
Chuck, Arm Pot Roast, braised	260 180	160 60	18 7	7 3	85 85	50 55	24 28	15 20
Chuck, Blade Roast, braised	290 210	190 100	21 11	9 4	90 90	55 60	23 26	15 15
Rib Roast, Large End, roasted	300 200	220 100	24 11	10 4	70 70	55 60	20 23	10 15
Rib Steak, Small End, broiled	280 190	190 90	21 10	9 4	70 70	55 60	20 24	10 10
Top Loin, Steak, broiled	230 180	130 70	15 8	6 3	65 65	55 60	22 24	10 10
Loin, Tenderloin Steak, broiled	240 180	150 80	16 9	6 3	75 70	50 55	22 24	15 15
Loin, Sirloin Steak, broiled	210 170	110 60	12 6	5 2	75 75	55 55	24 26	15 15
Eye Round, Roast, roasted	170 140	60 40	7 4	3 2	60 60	50 55	24 25	10 10
Bottom Round, Steak, braised	220 180	110 60	12 7	5 2	80 80	40 45	25 27	15 15
Round, Tip Roast, roasted	190 160	90 50	10 6	4 2	70 70	55 55	23 24	15 15
Top Round, Steak, broiled	180 150	70 40	7 4	3 1	70 70	50 50	26 27	15 15
VEAL, 3 oz cooked serving			g	g	mg	mg	g	%DV
Shoulder, Arm Steak, braised	200 170	80 40	9 5	3 1	125 130	75 75	29 30	6 6
Shoulder, Blade Steak, braised	190 170	80 50	9 6	3 2	130 135	85 85	27 28	6 6
Rib Roast, roasted	190 150	110 60	12 6	5 2	95 95	80 80	20 22	4 4
Loin Chop, roasted	180 150	100 50	10 6	4 2	85 90	80 80	21 22	4 4
Cutlets, roasted	140 130	35 25	4 3	2 1	85 90	60 60	24 24	4 4

Not a significant source of total carbohydrate, dietary fiber, sugars, vitamin A, vitamin C, and calcium.

*Before cooking

Serving Size: 3 oz. cooked portion, without added fat, salt or sauces.

Developed By: Food Marketing Institute, American Dietetic Association, American Meat Institute, National-American Wholesale Grocers' Association, National Broiler Council, National Fisheries Institute, National Grocers Association, National Live Stock and Meat Board, National Turkey Federation, United Fresh Fruit and Vegetable Association.

Reviewed By: United States Department of Agriculture

Data Source: USDA Handbook 8-13, *revised 1990* and *Bulletin Board, 1994* (beef) and USDA Handbook 8-17, 1989 (veal)

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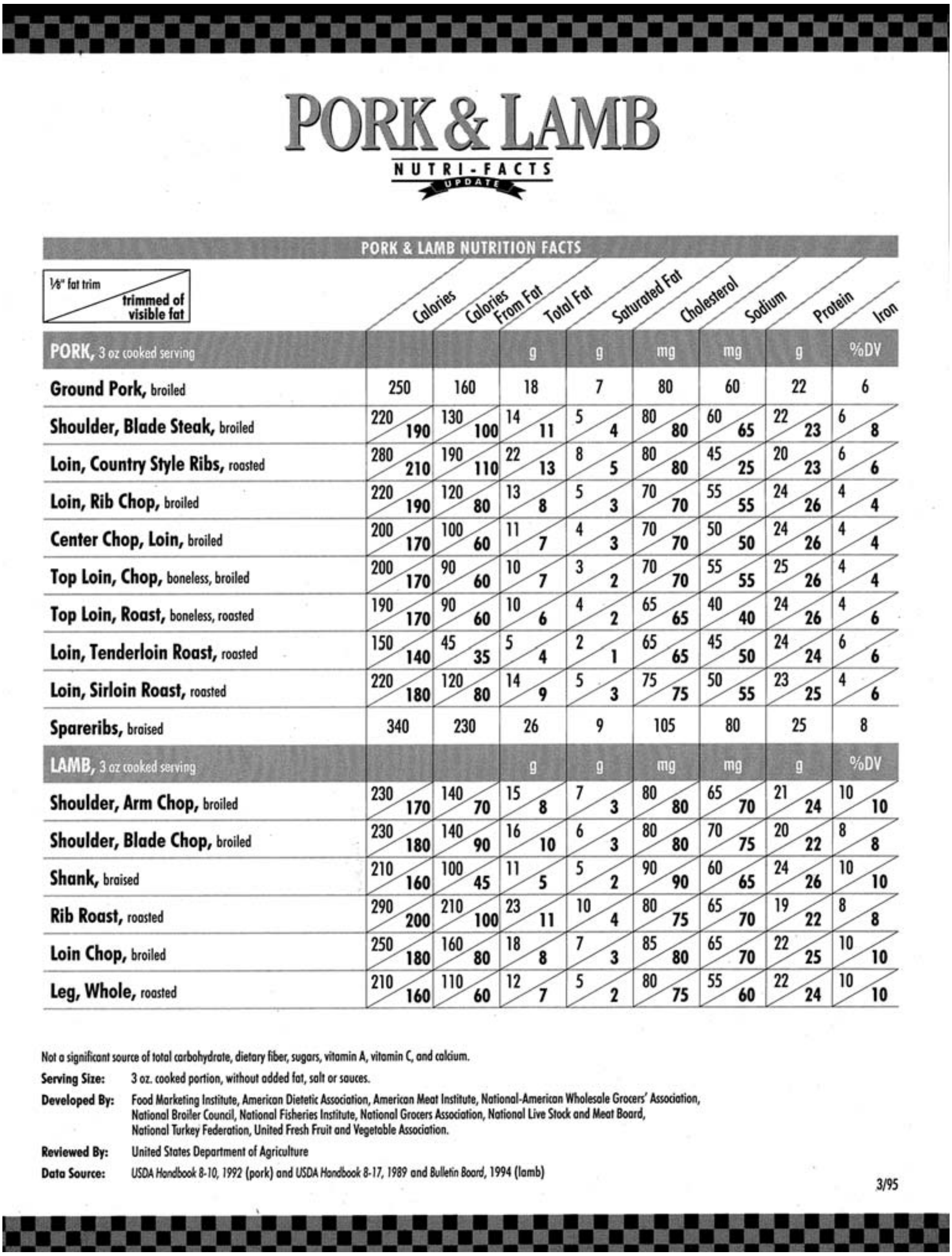
FIGURE 9.11 Nutrifacts of beef and veal in 3-ounce cooked portions (*Source*: Food Marketing Institute).



PORK & LAMB

NUTRI-FACTS

UPDATE

PORK & LAMB NUTRITION FACTS

⅛" fat trim / trimmed of visible fat

PORK, 3 oz cooked serving	Calories	Calories From Fat	Total Fat g	Saturated Fat g	Cholesterol mg	Sodium mg	Protein g	Iron %DV
Ground Pork, broiled	250	160	18	7	80	60	22	6
Shoulder, Blade Steak, broiled	220 190	130 100	14 11	5 4	80 80	60 65	22 23	6 8
Loin, Country Style Ribs, roasted	280 210	190 110	22 13	8 5	80 80	45 25	20 23	6 6
Loin, Rib Chop, broiled	220 190	120 80	13 8	5 3	70 70	55 55	24 26	4 4
Center Chop, Loin, broiled	200 170	100 60	11 7	4 3	70 70	50 50	24 26	4 4
Top Loin, Chop, boneless, broiled	200 170	90 60	10 7	3 2	70 70	55 55	25 26	4 4
Top Loin, Roast, boneless, roasted	190 170	90 60	10 6	4 2	65 65	40 40	24 26	4 6
Loin, Tenderloin Roast, roasted	150 140	45 35	5 4	2 1	65 65	45 50	24 24	6 6
Loin, Sirloin Roast, roasted	220 180	120 80	14 9	5 3	75 75	50 55	23 25	4 6
Spareribs, braised	340	230	26	9	105	80	25	8
LAMB, 3 oz cooked serving			g	g	mg	mg	g	%DV
Shoulder, Arm Chop, broiled	230 170	140 70	15 8	7 3	80 80	65 70	21 24	10 10
Shoulder, Blade Chop, broiled	230 180	140 90	16 10	6 3	80 80	70 75	20 22	8 8
Shank, braised	210 160	100 45	11 5	5 2	90 90	60 65	24 26	10 10
Rib Roast, roasted	290 200	210 100	23 11	10 4	80 75	65 70	19 22	8 8
Loin Chop, broiled	250 180	160 80	18 8	7 3	85 80	65 70	22 25	10 10
Leg, Whole, roasted	210 160	110 60	12 7	5 2	80 75	55 60	22 24	10 10

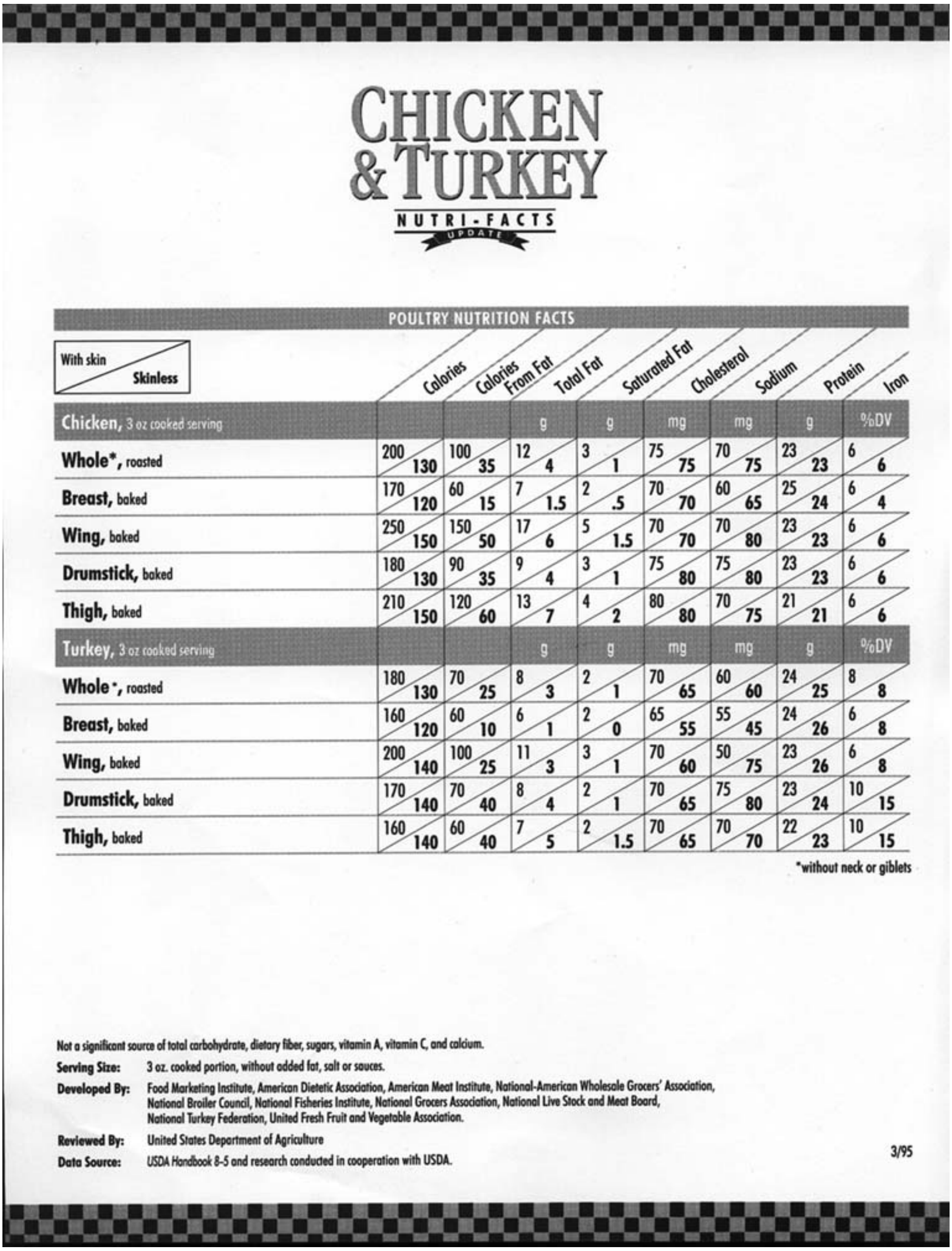
Not a significant source of total carbohydrate, dietary fiber, sugars, vitamin A, vitamin C, and calcium.

Serving Size:	3 oz. cooked portion, without added fat, salt or sauces.
Developed By:	Food Marketing Institute, American Dietetic Association, American Meat Institute, National-American Wholesale Grocers' Association, National Broiler Council, National Fisheries Institute, National Grocers Association, National Live Stock and Meat Board, National Turkey Federation, United Fresh Fruit and Vegetable Association.
Reviewed By:	United States Department of Agriculture
Data Source:	*USDA Handbook 8-10*, 1992 (pork) and *USDA Handbook 8-17*, 1989 and *Bulletin Board*, 1994 (lamb)

3/95

FIGURE 9.12 Nutrifacts of pork and lamb in 3-ounce cooked portions (*Source*: Food Marketing Institute).

Nutritive values for calories, calories from fat, total fat, saturated fat, cholesterol, sodium, protein, and iron are reported for beef and veal, pork and lamb, and chicken and turkey. Calories, calories from fat, total fat, saturated fat, cholesterol,



CHICKEN & TURKEY

NUTRI-FACTS

UPDATE

POULTRY NUTRITION FACTS

With skin Skinless	Calories	Calories From Fat	Total Fat	Saturated Fat	Cholesterol	Sodium	Protein	Iron
Chicken, 3 oz cooked serving			g	g	mg	mg	g	%DV
Whole*, roasted	200 130	100 35	12 4	3 1	75 75	70 75	23 23	6 6
Breast, baked	170 120	60 15	7 1.5	2 .5	70 70	60 65	25 24	6 4
Wing, baked	250 150	150 50	17 6	5 1.5	70 70	70 80	23 23	6 6
Drumstick, baked	180 130	90 35	9 4	3 1	75 80	75 80	23 23	6 6
Thigh, baked	210 150	120 60	13 7	4 2	80 80	70 75	21 21	6 6
Turkey, 3 oz cooked serving			g	g	mg	mg	g	%DV
Whole*, roasted	180 130	70 25	8 3	2 1	70 65	60 60	24 25	8 8
Breast, baked	160 120	60 10	6 1	2 0	65 55	55 45	24 26	6 8
Wing, baked	200 140	100 25	11 3	3 1	70 60	50 75	23 26	6 8
Drumstick, baked	170 140	70 40	8 4	2 1	70 65	75 80	23 24	10 15
Thigh, baked	160 140	60 40	7 5	2 1.5	70 65	70 70	22 23	10 15

*without neck or giblets

Not a significant source of total carbohydrate, dietary fiber, sugars, vitamin A, vitamin C, and calcium.

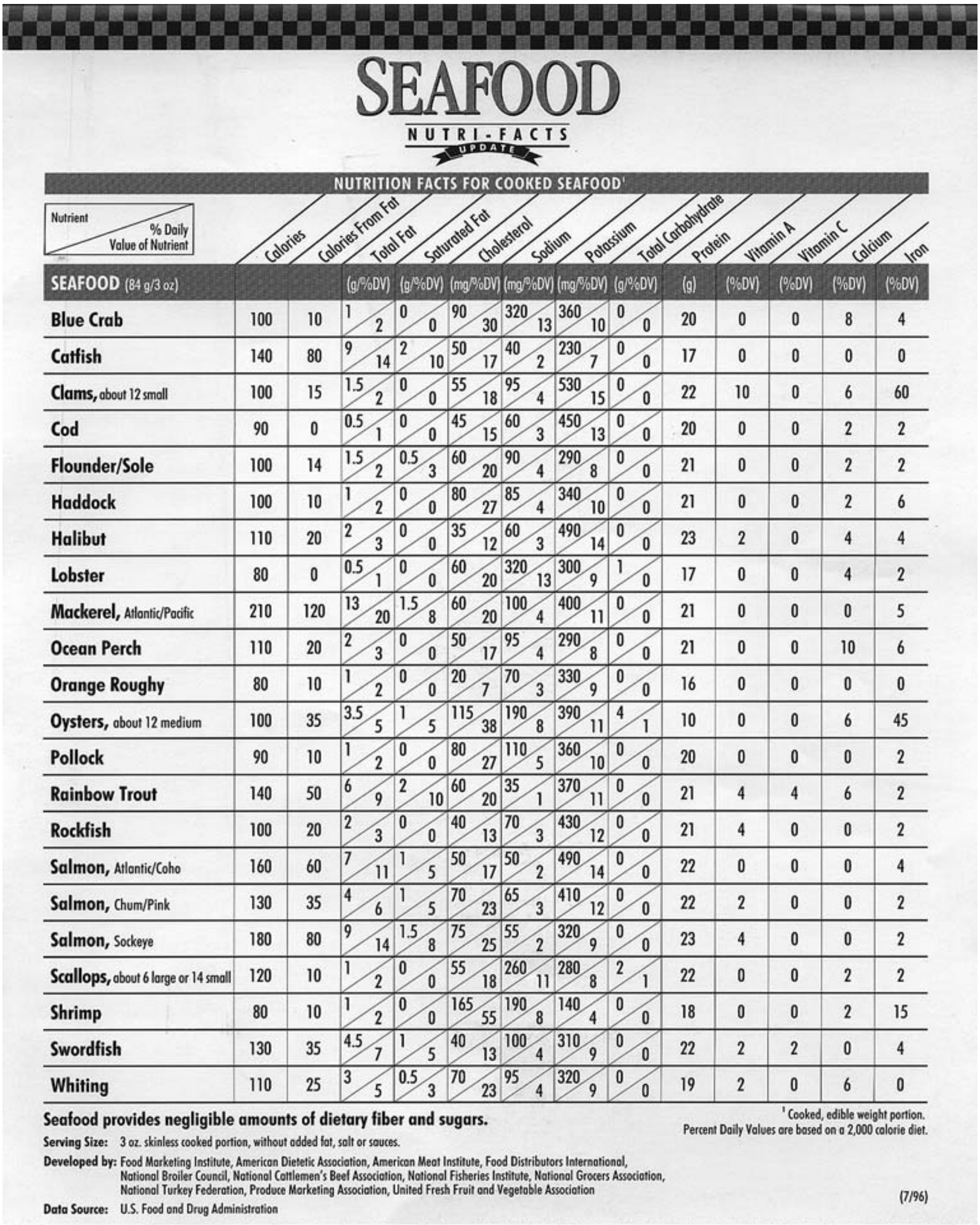
Serving Size:	3 oz. cooked portion, without added fat, salt or sauces.
Developed By:	Food Marketing Institute, American Dietetic Association, American Meat Institute, National-American Wholesale Grocers' Association, National Broiler Council, National Fisheries Institute, National Grocers Association, National Live Stock and Meat Board, National Turkey Federation, United Fresh Fruit and Vegetable Association.
Reviewed By:	United States Department of Agriculture
Data Source:	USDA Handbook 8-5 and research conducted in cooperation with USDA.

3/95

FIGURE 9.13 Nutrifacts of chicken and turkey in 3-ounce cooked portions (*Source*: Food Marketing Institute).

sodium, potassium, total carbohydrate, protein, vitamin A, vitamin C, calcium, and iron also are reported for seafood.

Meats are excellent sources of complete protein, many B vitamins, including B_{12} which is only found in animal products and also the minerals iron and zinc.



SEAFOOD

NUTRI-FACTS

UPDATE

NUTRITION FACTS FOR COOKED SEAFOOD[1]

Nutrient / % Daily Value of Nutrient SEAFOOD (84 g/3 oz)	Calories	Calories From Fat	Total Fat (g/%DV)	Saturated Fat (g/%DV)	Cholesterol (mg/%DV)	Sodium (mg/%DV)	Potassium (mg/%DV)	Total Carbohydrate (g/%DV)	Protein (g)	Vitamin A (%DV)	Vitamin C (%DV)	Calcium (%DV)	Iron (%DV)
Blue Crab	100	10	1 / 2	0 / 0	90 / 30	320 / 13	360 / 10	0 / 0	20	0	0	8	4
Catfish	140	80	9 / 14	2 / 10	50 / 17	40 / 2	230 / 7	0 / 0	17	0	0	0	0
Clams, about 12 small	100	15	1.5 / 2	0 / 0	55 / 18	95 / 4	530 / 15	0 / 0	22	10	0	6	60
Cod	90	0	0.5 / 1	0 / 0	45 / 15	60 / 3	450 / 13	0 / 0	20	0	0	2	2
Flounder/Sole	100	14	1.5 / 2	0.5 / 3	60 / 20	90 / 4	290 / 8	0 / 0	21	0	0	2	2
Haddock	100	10	1 / 2	0 / 0	80 / 27	85 / 4	340 / 10	0 / 0	21	0	0	2	6
Halibut	110	20	2 / 3	0 / 0	35 / 12	60 / 3	490 / 14	0 / 0	23	2	0	4	4
Lobster	80	0	0.5 / 1	0 / 0	60 / 20	320 / 13	300 / 9	1 / 0	17	0	0	4	2
Mackerel, Atlantic/Pacific	210	120	13 / 20	1.5 / 8	60 / 20	100 / 4	400 / 11	0 / 0	21	0	0	0	5
Ocean Perch	110	20	2 / 3	0 / 0	50 / 17	95 / 4	290 / 8	0 / 0	21	0	0	10	6
Orange Roughy	80	10	1 / 2	0 / 0	20 / 7	70 / 3	330 / 9	0 / 0	16	0	0	0	0
Oysters, about 12 medium	100	35	3.5 / 5	1 / 5	115 / 38	190 / 8	390 / 11	4 / 1	10	0	0	6	45
Pollock	90	10	1 / 2	0 / 0	80 / 27	110 / 5	360 / 10	0 / 0	20	0	0	0	2
Rainbow Trout	140	50	6 / 9	2 / 10	60 / 20	35 / 1	370 / 11	0 / 0	21	4	4	6	2
Rockfish	100	20	2 / 3	0 / 0	40 / 13	70 / 3	430 / 12	0 / 0	21	4	0	0	2
Salmon, Atlantic/Coho	160	60	7 / 11	1 / 5	50 / 17	50 / 2	490 / 14	0 / 0	22	0	0	0	4
Salmon, Chum/Pink	130	35	4 / 6	1 / 5	70 / 23	65 / 3	410 / 12	0 / 0	22	2	0	0	2
Salmon, Sockeye	180	80	9 / 14	1.5 / 8	75 / 25	55 / 2	320 / 9	0 / 0	23	4	0	0	2
Scallops, about 6 large or 14 small	120	10	1 / 2	0 / 0	55 / 18	260 / 11	280 / 8	2 / 1	22	0	0	2	2
Shrimp	80	10	1 / 2	0 / 0	165 / 55	190 / 8	140 / 4	0 / 0	18	0	0	2	15
Swordfish	130	35	4.5 / 7	1 / 5	40 / 13	100 / 4	310 / 9	0 / 0	22	2	2	0	4
Whiting	110	25	3 / 5	0.5 / 3	70 / 23	95 / 4	320 / 9	0 / 0	19	2	0	6	0

Seafood provides negligible amounts of dietary fiber and sugars.

[1] Cooked, edible weight portion.
Percent Daily Values are based on a 2,000 calorie diet.

Serving Size: 3 oz. skinless cooked portion, without added fat, salt or sauces.

Developed by: Food Marketing Institute, American Dietetic Association, American Meat Institute, Food Distributors International, National Broiler Council, National Cattlemen's Beef Association, National Fisheries Institute, National Grocers Association, National Turkey Federation, Produce Marketing Association, United Fresh Fruit and Vegetable Association

Data Source: U.S. Food and Drug Administration

(7/96)

FIGURE 9.14 Nutrifacts of seafood in 3-ounce cooked portions (*Source*: Food Marketing Institute).

For additional information on the nutritive value of meat and its many vitamins and minerals, the reader is referred to other nutrition textbooks.

Soybeans have antioxidant properties and contain saponins noted for their disease-fighting potential. In 1999, the FDA issued a health claim stating that the consumption of a minimum of 25 g of soy protein per day, coupled with a low-fat, low-cholesterol diet, may reduce risk of coronary heart disease. In 2000, the American Heart Association announced the organization's official recommendation for daily consumption of soy protein.

SAFETY

A lot has been said about meat in this chapter; however, safety is of utmost concern. Meat is a potentially hazardous food that supports rapid bacterial growth if stored at improper temperatures (Chapter 16). Because all meat contains bacteria, it should be maintained in a clean and covered condition at temperatures that retard the growth of microorganisms which may both contaminate and spoil meat, producing changes in the color, odor, and safety. *Safe handling* instructions appearing on meat packages is shown in Figure 9.11.

The CDC reports a sustained decline in reported illnesses from several bacteria including *Listeria, Campylobacter, and Salmonella* over the last few years since 1996. It is attributed in part to "...a change in the way that food safety in meat slaughter, animal slaughter and processing is managed" (CDC).

The USDA Deputy Undersecretary of food safety said "We are strongly encouraging specific interventions for raw meat and poultry in order to further reduce the level and incidence of pathogens such as *Salmonella* in these products. We feel that there is a whole arsenal of potentially effective interventions that could be utilized" (CDC).

CULINARY ALERT! Adherence to specific temperatures is necessary for the prevention of growth and the destruction of harmful microorganisms in meat. Adequate refrigeration, cooking, and holding, as well as reheating, are all important in controlling bacteria. Personal hygiene and sanitation also are important in preventing the spread of bacteria.

The bacteria *Clostridium botulinum* is an *anaerobic* bacteria that causes the disease botulism. It is a deadly form of food poisoning that may result from consuming improperly processed canned or vacuum-packed meats. To control this, nitrite may be added to processed meat to inhibit the reproduction of bacterial spores.

A more common, less deadly bacteria such as *Staphylococcus aureus* may grow in contaminated meat products. Subsequently, the bacteria may be destroyed in cooking; however, the toxin that the bacteria secrete survives cooking and may cause food poisoning. Illness becomes apparent in as little as 1 hour after consumption of contaminated meat.

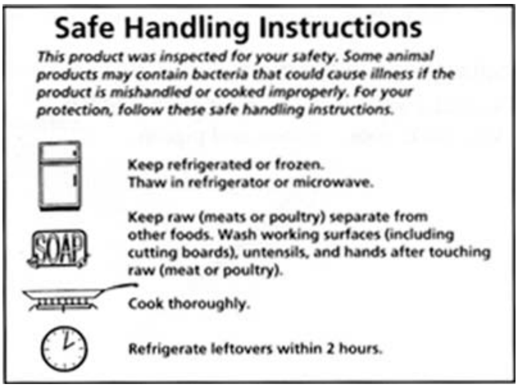
Without sufficient cooking, poultry may contain the live, infection-causing *Salmonella* bacteria, which is the most common cause of foodborne infections in the United States. Most *Salmonella* are destroyed at 161° F(72° C) for 16 seconds or 143° F(62° C) for 30 minutes. Another *Clostridium*, *Clostridium perfringens*, is found in meats, especially those that were allowed to cool slowly following cooking. Undercooked pork may contain the parasite *Trichinella spiralis*, which is killed at temperatures of 155° F(68° C).

Ground beef, the *combined* meat from *many* cattle, is more likely to have contamination with *E. coli 0157:H7* than is a *single* cut of meat (such as steak) coming from a *single* animal. Bacteria may spread during processing and handling; then cooking temperatures of 155° F(68° C) are necessary to destroy any *E. coli* that might be in the meat. A major challenge to the safety of ready-to-eat products includes *Listeria monocytogenes.* This may grow under refrigeration, yet is destroyed by thermal processing.

The USDA gave approval for *steam pasteurization* as an antimicrobial treatment of beef carcasses (see below). This treatment reduces the risk of *E. coli 0157:H7* by exposing the entire surface of the carcass to steam that kills the bacteria. Meat processors must avoid subsequent recontamination of the product and the consumer must handle the meat with care. The use of steam pasteurization for *pork and poultry* is subject to further research.

The American Meat Institute Foundation (AMIF) speaks for the industry in saying that it *sanitizes* fresh meat, as well as the ready-to-eat meat products, including hams and hot dogs. This sanitization is achieved either by steam pasteurization, which (1) exposes the carcass to a steam filled cabinet, or (2) uses of a handheld device in steam vacuuming, whereby steam is sprayed directly onto carcass spots where contamination is suspected. With the added food protection provided by the uses of multiple intervention strategies, sprays and organic acid (lactic and acetic acids) and hot water treatment also are used widely (5).

Other FDA approved treatments include high-intensity pulsed-light treatment for the control of microorganisms on the surface of food (61 FR42381-42382). Irradiation is a process often used to destroy the pathogens that are present in meat and extend refrigerator shelf life. The FDA has approved *radiation* of fresh, frozen meats such as beef, lamb, and pork to control disease-causing microorganisms (Chapter 16).



Safe Handling Instructions

This product was inspected for your safety. Some animal products may contain bacteria that could cause illness if the product is mishandled or cooked improperly. For your protection, follow these safe handling instructions.

Keep refrigerated or frozen. Thaw in refrigerator or microwave.

Keep raw (meats or poultry) separate from other foods. Wash working surfaces (including cutting boards), untensils, and hands after touching raw (meat or poultry).

Cook thoroughly.

Refrigerate leftovers within 2 hours.

FIGURE 9.15 Safe handling instructions (*Source*: USDA).

TABLE 9.1 Minimum Safe Internal Temperature for Selected Meats

Meat	Temperature
Beef steaks (rare)	155° F(68° C) (to customer order)
Roast beef (rare)	130° F(54° C) (time dependent)
Pork	155° F(68° C) or 170° F(77° C) in a microwave oven
Ground beef	155° F(68° C)
Poultry	165° F(74° C)

Source: FDA.

A US patent recently was awarded to a company that uses electricity as the energy source to pasteurize processed and packaged foods, including ready-to-eat meats such as hot dogs and luncheon meats (4). The use of *ozone* to disinfect poultry processing water is reviewed on a case-by-case basis.

CULINARY ALERT! Meat must be kept safe in the defrosting process. The FDA advises thawing below temperatures of 45° F(7° C), under cold running water or by microwave if immediately cooked. Slow thawing, with intact wrappers, is the defrosting method that allows the least moisture loss. The USDA recommends refreezing only in the case of properly thawed and cooked meats.

The FDA recommended cooking temperatures to control bacterial growth and prevent foodborne illness are listed in Table 9.1 (check local jurisdiction).

Current concern exists over *Bovine Spongiform Encephalopathy* (BSE) or "*mad cow disease*." As many individuals, groups, and governments attempt to manage this disease, quarantine, slaughter, and infection by animal feed made from other infected cattle as well as hysteria and false alarms may be "issues." Further understanding of the disease and vigilance is needed to protect the food supply.

Much has been written about diseased meat and its prevention and cure. For example, more than one million copies of an informational document by NCBA have been financially supported and distributed in the United States to address foot-and mouth disease (FMD) and *bovine spongiform encephalopathy*. "FMD & BSE: What Every Producer Needs to Know" addresses, among other issues, prevention, FAQ, as well as the government's emergency response.

CONCLUSION

Meat is the edible portion of animals used for food. Beef, pork, lamb, and veal are included in the definition of meat, and other animal products such as poultry and fish are commonly considered to be "meats." The amount and type of meat consumption varies throughout the world. Meat primarily is a muscle tissue and also contains connective tissue with a greater variance in the amount of adipose tissue held inside. Water is present to a greater degree in lean meats and young animals. The protein is a complete protein and contains all the essential amino acids.

Cuts of meat include primal or wholesale, subprimal, and retail cuts, with the latter being more familiar to consumers, as it is what they may purchase at their grocery market. The inherent tenderness of a particular cut depends on such factors as location on the carcass, postmortem changes in the muscle, including the stage of rigor mortis, aging, and the method of cooking. Meat color such as red or white or "dark meat" is dependent on myoglobin and hemoglobin pigments. Changes in the color of meat may result from exposure to oxygen, acidity, and light.

Meat is subject to inspections and grading in order to provide the consumer with safe, more consistent and reliable meat products. Meat is a potentially hazardous food and adherence to specific temperatures (cold and hot) is necessary for the prevention of growth and the destruction of harmful microorganisms.

Cooking meat causes the uncoiling or denaturation of peptide protein chains to occur. Tender cuts of meat remain tender when cooked by dry heat for a short time at high temperatures. Overcooking tender cuts of meat produces tough, dry meat, because water is released during denaturation. Less tender cuts of meat become increasingly tender as collagen solubilizes during lengthy exposure to moist heat cooking.

Beef, veal, pork, and lamb may be altered by various processing methods. This includes restructuring and artificial tenderizing. Ham, corned beef, and bacon are examples of cured meat. Beef, ham, and turkey may be smoked to impart flavor and offer microbial control by dehydration. An alteration to meat occurs as meat is artificially tenderized and includes mechanical, electrical, and enzymatic treatment.

Poultry makes a significant contribution to the US diet and is classified according to age and condition of the bird. Many processed poultry products, including ground turkey, lunchmeats, and formed entrees are available for use by consumers. Edible fish and shellfish, including restructured fish such as surimi, provide high-quality protein food to the diet.

Various legumes are consumed. They are incomplete proteins and when combined they function as meat alternatives.

GLOSSARY

Actin: The protein of muscle that is contained in the thin myofilaments and is active in muscle contraction.

Actomyosin: The compound of actin and myosin that forms in muscle contraction.

Adipose tissue: Fatty tissue; energy storage area in an animal.

Aging: Process in which muscles become more tender due to protein breakdown.

Collagen: Connective tissue protein; the largest component that gives strength to connective tissue; is solubilized to gelatin with cooking.

Connective tissue: The component of animal tissue that extends beyond the muscle fibers to form tendons which attach the muscle to bones; it connects bone to bone; endomysium, perimysium, and epimysium connective tissue surrounds muscle fibers, muscle bundles, and whole muscles, respectively.

Cured meat: Contains nitrite to form the pink color and control the growth of *Clostridium botulinum*.

Dry heat: Method of cooking tender cuts of meat, including broiling, frying, pan frying, and roasting.

Elastin: Connective tissue protein; the yellow component of connective tissue that holds bone and cartilage together.

Endomysium: Connective tissue layer that surrounds individual muscle fibers.

Epimysium: Connective tissue layer that surrounds an entire muscle.

Gelatin: Formed from the tenderization of collagen, used for edible gels in the human diet.

Grain: Primary bundle containing 20–40 muscle fibrils.

Halal: “Proper and permitted” food under jurisdiction of trained Muslim inpection.

Kosher: “Fit and proper” or “properly prepared” food under jurisdiction of the Jewish faith; following the Mosaic or Talmudic Law.

Marbled: Intermuscular and intramuscular fatty tissue distributed in meat.

Moist heat: Method of cooking less tender cuts of meat, including braising, pressure cooking, simmering, or stewing.

Muscle tissue: The lean tissue of meat.

Myofibril: The contractile actin and myosin elements of a muscle cell.

Myosin: Protein of a muscle contained in the thick myofilaments that reacts with actin to form actomyosin.

Perimysium: The connective tissue layer that surrounds muscle bundles.

Primal cut: Wholesale cut of meat; it contains the subprimal and retail cuts.

Retail cut: Cuts of meat available in the retail market; cut from primal cuts.

Reticulin: Minor connective tissue found in younger animals; it may be the precursor of collagen or elastin.

Rigor mortis: Postmortem state 6–24 hours after death in which muscles stiffen and become less extensible; onset of rigor mortis correlates with depletion of ATP in the slaughtered animal.

Sarcomere: Repeating unit of the muscle myofibrils.

Sarcoplasmic protein: The hemoglobin and myoglobin pigments and enzymes in the cytoplasm of a muscle fiber.

Smoked meat: Meat that has been treated to impart flavor by exposure to aromatic smoke of hardwood; smoking preserves by dehydrating, thus offering microbial control.

Stromal protein: Proteins including collagen, elastin, and reticulin of the connective tissue and supporting framework of an animal organ.

Subprimal cut: Division of a primal cut.

Wholesome: Inspection does not indicate the presence of illness.

Z-lines: Boundaries of the sarcomere; holds thin filaments in place in the myofibril.

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ASSOCIATIONS

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American Heart Association, Dallas, TX.
National Cattlemen's Beef Association—A merger of the National Livestock and Meat Board, and National Cattlemen's Association, Chicago, IL.
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CHAPTER 10

Eggs and Egg Products

INTRODUCTION

The eggs of various birds are consumed throughout the world; however, the discussion that follows is regarding *hen* eggs. Eggs are a natural biological structure with shells offering protection for developing chick embryos. They have numerous functions in food systems and must be protected against contamination. Eggs provide nutritive value and culinary variety to the diet, while being an economical source of food.

Eggs are considered by the World Health Organization (WHO) to be the reference protein worldwide, to which all other protein is compared. A vegetarian diet that includes eggs is an ovovegetarian diet.

The quality and freshness of eggs is important to regulatory agencies, processors, and consumers and is determined by a number of factors. The age, temperature, humidity, and handling of eggs determine freshness. Egg safety is significant.

PHYSICAL STRUCTURE AND COMPOSITION OF EGGS

The Whole Egg

An average hen egg weighs about 2 ounces (57 g), which includes the weight of the yolk, white, and shell. Each component differs in composition, as shown in Tables 10.1 and 10.2.

CULINARY ALERT! Egg protein includes the enzyme *alpha-amylase*. This enzyme must be inactivated by heat in order to have desirable cooked egg mixtures. Undercooked egg mixtures may not show a deleterious effect until after the egg has been refrigerated.

TABLE 10.1 Chemical Composition of the Hen's Egg by Percentage

Component	%	Water	Protein	Fat	Ash
Whole egg	100	65.5	11.8	11.0	11.7
Egg white	58	88.0	11.0	0.2	0.8
Egg yolk	31	48.0	17.5	32.5	2.0
Shell	11				

Source: USDA.

The Yolk

A cluster of developing yolks, each within its own sac, is present in the hen ovary. An egg yolk comprises approximately 31% of the weight of an egg, *all* of the egg's cholesterol and almost all of the fat. Generally, it has a *higher* nutrient density than the white, containing all of the vitamins known except vitamin C. Additionally, yolks supply flavor and mouthfeel that consumers find acceptable; they have many culinary uses.

Egg yolks contain all three *lipids* (triglycerides) fats and oils, phospholipids, and sterols in large spheres, granules, and micelles. The primary phospholipid is phosphatidyl choline, or *lecithin*; the most well-known sterol is *cholesterol* found only in the yolk.

Protein in the yolk is primarily vitellin which is present in a lipoprotein complex as lipovitellin and lipovitellinin. The phosphorus-containing phosvitin and sulfur-containing livetin also are present in yolks.

The yolk *pigments*, mainly xanthophylls, also carotene and lycopene, come from animal feed such as the green plants and yellow corn that the hen eats. If yolks have a higher carotenoid content, they are *darker* (although not necessarily of vitamin A potential); however, chickens producing eggs with *pale* yolks may be fed supplements that darken the yolk. Concentric rings of slightly different colors appear in the yolk, beginning in the center with a very small white spot. Green color of boiled eggs is discussed later.

TABLE 10.2 Protein and Fat Content of Egg Components in Grams

Component	Protein	Fat
Whole egg	6.5	5.8
Egg white	3.6	–
Egg yolk	2.7	5.2

Source: USDA.

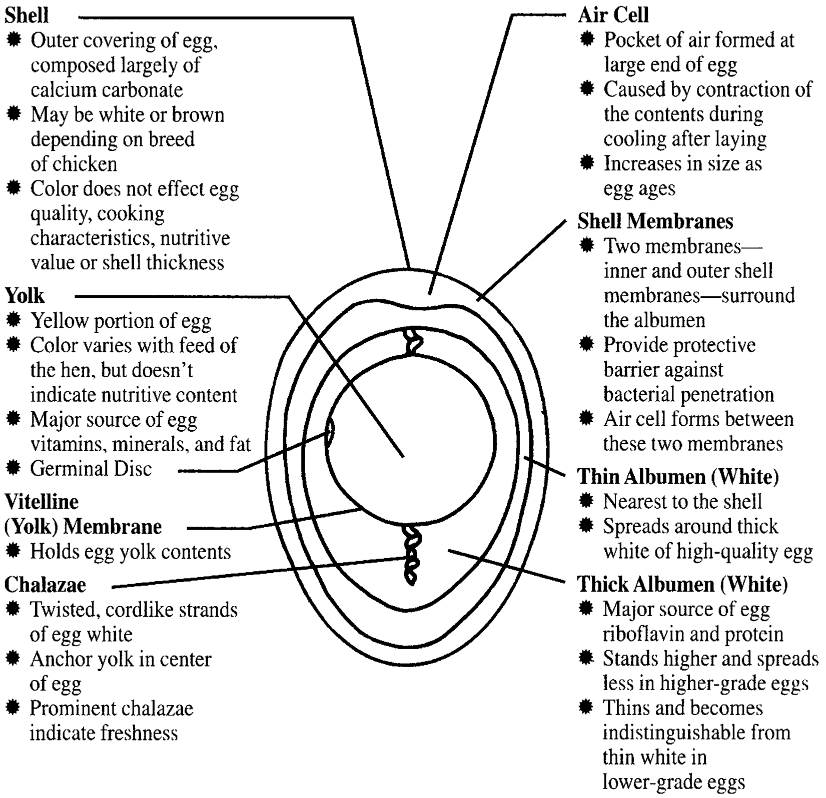


FIGURE 10.1 Structure of a hen's egg (*Source*: California Egg Commission).

There is a higher concentration of *solids* in the yolk than in the white, and thus water movement into the yolk occurs as the egg ages. This causes the egg yolks to enlarge and become less viscous.

Surrounding the yolk is a colorless sac, the **vitelline membrane** (Figure 10.1). It is continuous with the opaque colored chalazae (kah-lay-za) cord structure (Figure 10.1). The chalazae is a ropelike cord that attaches to the yolk vitelline membrane yet is actually found in the albumen, or white. It holds the yolk in place at the center of the egg, preventing it from the damaging effects of hitting the shell (similar to a bungi jumping cord!).

The White

The egg white, also known as the **albumen** (Figure 10.1), comprises approximately 58% of the weight of an egg. As with the yolk, the white too consists of concentric layers. There are four: two thick whites separated by inner and outer thin whites. In lower grade or older eggs, the thick albumen becomes *indistinguishable* from the thin whites. The chalazae is located within these layers of the albumen and is continuous with the vitelline membrane that surrounds the yolk. A fresh egg has a more prominent chalazae than older eggs.

Eggs contain a high biological value protein, which is a *complete* protein, with all of the essential amino acids in a well-balanced proportion. Over half of the protein in whites is *ovalbumin*, although conalbumin, ovomucid, and globulins (including lysozyme, which is able to lyse some bacteria) contribute lesser percentages of protein in the egg whites.

Whites provide *more* protein than the yolk and are often cooked and eaten alone or incorporated into a recipe. The addition of egg whites in place of an entire egg adds protein while limiting fat and cholesterol.

Avidin is another egg white protein. If consumed *raw*, the avidin binds with the vitamin biotin and renders biotin ineffective when consumed.

Egg white proteins attach themselves to the yolk as it descends down the oviduct of the hen. Other constituents of the white are a negligible amount of fat; the vitamins riboflavin (which imparts a greenish tint to the white), niacin, biotin; and minerals including magnesium and potassium.

The Shell

The shell contributes the remaining 11% weight of the whole egg. The dry shell contains the following:

- 94% calcium carbonate
- 1% magnesium carbonate
- 1% calcium phosphate
- 4% organic matrix made primarily of protein

Layers of the shell consist of a *mammillary* or inner layer, a *spongy* layer, and the outer *cuticle* (which may erroneously be referred to as "bloom"). The cuticle blocks the pores and protects the egg against outside contamination entering the egg.

Thousands of pores run throughout these layers of the shell, with a greater number at the large end. A shell is *naturally* porous for a potentially developing chick inside. As a result of the pores, CO_2 and moisture losses occur and O_2 enters the shell. The shell also functions as a barrier against harmful bacteria and mold entry, as a protein layer of keratin partially seals the shell pores.

"Sweating" or moisture condensation on the shell may produce stains. The presence of animal droppings also may stain. However, simply washing is *not* recommended as it may remove the shell's outer cuticle lining or open its pores, resulting in a diminished shelf life. Once the outside protection is violated, microorganisms from the outside can travel to the inside contents and contaminate the egg.

Two thin shell *membranes* (Figure 10.1) are inside of the shell, *one* of which is attached to the shell, and the *other* is not attached, but rather moves with the egg contents. The air cell (discussed later) develops as the two membranes separate at the large end of the egg.

Color

This section looks at both *shell* and *yolk* color. *Egg shell color* depends on the *breed* of hen and has *no* effect on egg flavor or quality, including the nutritive quality of the egg contents. *White Leghorn* hens are the chief breed for egg production in the United States and they produce *white* shells. Upon a closer look, it is significant that this *White* Leghorn breed of hen has *white* ears under their feathers.

Brown eggs (brown colored egg shells) are popular in some regions of the United States and with some individuals. Their eggs are from slightly larger birds (requiring more food) and they are not as prevalent as white shell eggs, therefore, for those reasons, brown eggs are usually more expensive than white. Brown eggs are produced from a *different* breed of hen than white eggs, notably hens with *reddish-brown* ears, such as *Rhode Island Red hens, Plymouth Rock hens, and New Hampshire breeds.*

Brown eggs are more difficult to classify by candling as to interior quality than are white eggs (USDA). In addition to the white and brown eggs, some egg shells are bluish or greenish. (Yes, the ears are of that same color tinge!)

The yolk color depends on the *feed* given to the hen. As mentioned earlier, yolks may be a *deep* yellow pigment due to carotene, xanthophyll, or lycopene in the feed (and not necessarily have vitamin A potential), or they may be *pale* yolks.

CULINARY ALERT! Color is not an indication of quality or nutritive value.

- Shell color – due to breed
- Yolk color – due to feed

Changes due to Aging

Numerous changes to the egg occur with age. Contents inside the shell *shrink* and the air cell (Figure 10.1) enlarges due to water loss (1). The yolk flattens as the vitelline membrane thins, and the surrounding thick white becomes thinner, no longer holding the yolk centered in the egg. Also, the thick white thins as sulfide bonds break and it loses CO_2 with age. Subsequently, the pH rises to a more alkaline level, from 7.6 to 9.6, which allows bacterial growth. Another change with age is that the chalazae cord appears less prominent.

Abnormalities of an Egg Structure and Composition

Abnormalities in the structure and composition of eggs may be detected with or without candling (see Candling). Consumers with firsthand experience may be familiar with some of these abnormalities. The USDA cites examples:

- Double-yolked egg—results when two yolks are released from the ovary about the same time or when one yolk is lost into the body cavity and then picked up when the ovary releases the next day's yolk.
- Yolkless eggs—usually formed around a bit of the tissue that is sloughed off the ovary or oviduct. This tissue stimulates the secreting glands of the oviduct and a yolkless egg results.

- Egg within an egg—one day's egg is reversed in direction by the wall of the oviduct and is added to the next day's egg. A shell is formed around both.
- Blood spots—rupture of one or more small blood vessels in the yolk follicle at the time of ovulation, although chemically and nutritionally they are fit to eat.
- Meat spots—either blood spots that have changed in color due to chemical action or tissue sloughed off from the reproductive organs of the hen.
- Soft-shelled eggs—generally occur when an egg is prematurely laid and insufficient time in the uterus prevents the deposit of the shell (eg, minerals).
- Thin-shelled eggs—may be caused by mineral deficiencies, heredity, or disease.
- Glassy- and chalky-shelled eggs—caused by malfunctions of the uterus of the laying bird. Glassy eggs are less porous and will not hatch but may retain their quality.
- Off-colored yolks—due to substances in feed that cause off-color.
- Off-flavored eggs—may be due to certain feed flavors, such as fish oil or garlic. Eggs stored near some fruits and vegetables or chemicals readily absorb odors from these products.

EGG FUNCTION

The function of eggs is important to the processing facilities, retail food service operations, and the consumer alike, who depend on eggs for many uses in food preparation. Due to the any number of functions of an egg, a recipe formulation without eggs may not exhibit the same qualities as one that contains eggs.

Perhaps the contents of eggs are not ingested. Contents may be discarded and the egg shell used empty or decorated for use in various ethnic holiday celebrations. Eggs are polyfunctional products.

CULINARY ALERT! Some of the functions of eggs are listed in Table 10.3.

A high-quality egg that is fit for the consumer is one without blemishes and with a shell that is intact and clean

INSPECTIONS AND GRADING FOR EGG QUALITY

The United States Department of Agriculture (USDA) grades eggs on a fee-for-service basis in order to assign grades. Grading involves an evaluation of the exterior shell, its shape, texture, soundness (not broken), and cleanliness, as well as the interior white and yolk and air cell size, and at least 80% of a dozen eggs must be the grade specified on the carton. Lesser grades and older eggs may be used successfully in other applications than high-grade, fresh eggs.

The 1970 Federal Egg Products Inspection Act provides the assurance that egg products are *wholesome and unadulterated* and that plants processing egg products are *continuously inspected*. Grading though is voluntary, although most eggs on the

TABLE 10.3 Some of the Functions of Eggs in Food Systems

- ***Binder***

Eggs are viscous and they coagulate (to a solid or semisolid state); therefore, they bind ingredients such as those in meatloaf or croquettes and they bind breading.

- ***Clarifying agent***

Raw egg whites coagulate around foreign particles in a hot liquid. For example, when added to liquid, eggs whites seize loose coffee grounds in a coffee pot and they clarify broth and soups, bringing the stray material to the surface for subsequent removal.

- ***Emulsifier***

Egg yolks contain phospholipid emulsifiers, including lecithin. Emulsifiers allow two ordinarily immiscible liquids, such as oil and water, to mix in the preparation of mayonnaise.

- ***Foaming, leavening agent, aeration***

Egg whites increase six to eight times in volume when beaten to a *foam*. As the egg white foam is heated, the protein coagulates around air cells, maintaining a stable foam structure. Egg white foams leaven angel food cake and are created for meringues and desserts.

- ***Gel***

A two-phase system of liquids in solids forms as eggs coagulate, forming a gel in custards.

- ***Thickening agent***

Eggs coagulate and thicken mixtures such as custards and hollandaise sauce.

- ***Other***

Color, flavor, nutritive value, surface drying and crisping, and so on. Eggs serve numerous other roles in foods.

Egg yolk carotenoids add yellowish color to baked products or yolks may be spread on dough to brown, dry, glaze, and impart a crusty sheen.

Fat provides flavor, *inhibits crystal formation* in sugars, and inhibits staling.

Eggs provide *nutritional value* in cooked or baked food mixtures.

retail market are graded under federal inspections (2), according to established standards.

Candling

Candling is a technique that allows a view of the shell and *inside* of eggs without breaking the shell; double yolks and so forth may be seen. Candlelight was once used for inspecting the interior of eggs, where egg contents could be seen when held up to a candle while being rapidly rotated. Today, commercial eggs may be scanned in mass, with bright lights under trays of eggs. The USDA bases grades on candling quality, evaluated either by hand (Figure 10.2) or by mass scanning (Figure 10.3).

Candling may be completed *either* at the farm or at the egg distributor before eggs are sold to the consumer. *External* observation of the shape and cleanliness of the shell may occur prior to or subsequent to candling. A candler also will

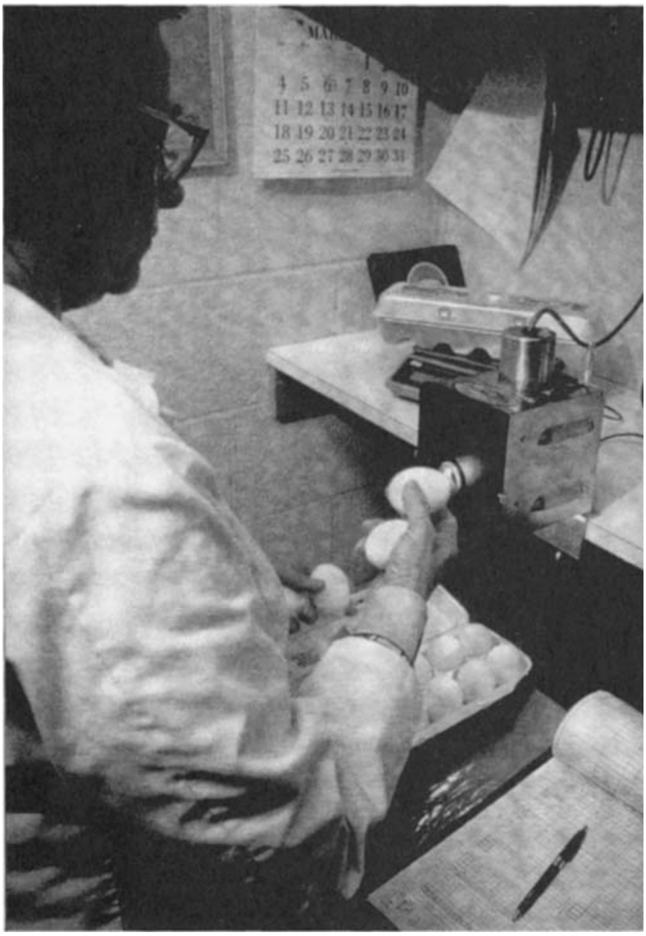


FIGURE 10.2 Candling eggs by hand (*Source*: USDA).

FIGURE 10.3 Candling by mass screening (*Source*: USDA).

form occasional comparisons of broken-out, internal appearance evaluation with candled appearance.

CULINARY ALERT! Blood spots may be undesirable to some consumers; however, they pose no health hazard.

Letter Grades

Letter grades are issued voluntarily. Letter grades are based on candled quality and may appear as shields on the egg cartons. Grade shields on the carton indicate that the eggs were graded for quality and checked for size under the supervision of a trained packer. Packers who do *not* choose to use the federal USDA grading service are monitored by *state* agencies and may *not* use the federal USDA grade shield.

The USDA grade shields are shown in Figure 10.4. The USDA assigns a grade of "AA" to the highest quality egg. Even this high quality may quickly diminish if eggs are exposed to improper storage conditions (2).

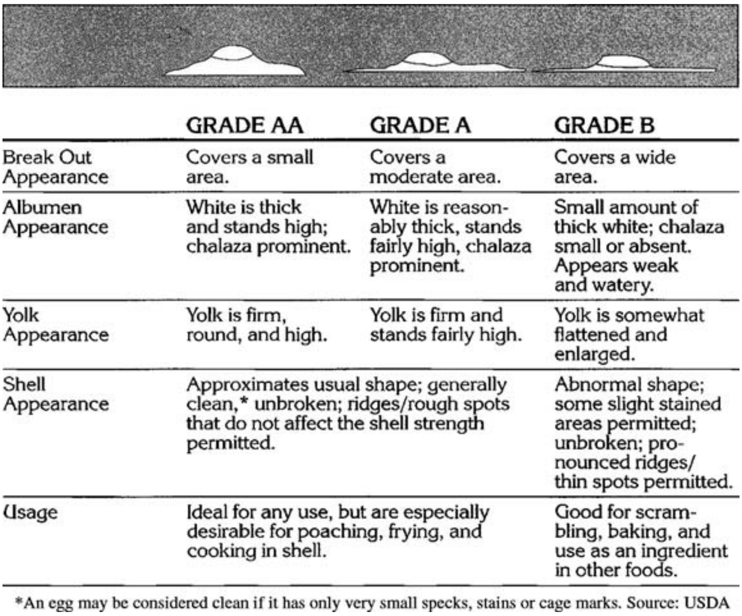
Occasional micrometer measurements of thick albumen egg height also may be carried out in a grading office where samples are tested (See Figures 10.5 and 10.6). An **"AA" egg** has:

- A thick white, prominent, chalazae cord. The height of the broken-out white is measured in Haugh units (with a micrometer) and compared to weight.
- A yolk must be round, high, and free from apparent defects. A flattened yolk indicates that the vitelline membrane has weakened with age or by poor storage conditions. The height is measured in relation to width.
- An air cell that may not exceed 1/18 inch in depth.
- A shell that must be clean and unbroken.

"A" grade indicates that:

- An egg is clear, reasonably thick, and stands high.
- The yolk must be practically free from apparent defects.
- The air cell must not exceed 3/16 inch in depth.
- The shell must be unbroken.

FIGURE 10.4 USDA emblem certifying quality (*Source*: USDA).



	GRADE AA	GRADE A	GRADE B
Break Out Appearance	Covers a small area.	Covers a moderate area.	Covers a wide area.
Albumen Appearance	White is thick and stands high; chalaza prominent.	White is reasonably thick, stands fairly high, chalaza prominent.	Small amount of thick white; chalaza small or absent. Appears weak and watery.
Yolk Appearance	Yolk is firm, round, and high.	Yolk is firm and stands fairly high.	Yolk is somewhat flattened and enlarged.
Shell Appearance	Approximates usual shape; generally clean,* unbroken; ridges/rough spots that do not affect the shell strength permitted.		Abnormal shape; some slight stained areas permitted; unbroken; pronounced ridges/thin spots permitted.
Usage	Ideal for any use, but are especially desirable for poaching, frying, and cooking in shell.		Good for scrambling, baking, and use as an ingredient in other foods.

*An egg may be considered clean if it has only very small specks, stains or cage marks. Source: USDA

FIGURE 10.5 Grades of eggs
(*Source*: California Egg Commission).

"B" grade eggs:

- Cover a wider area when broken open and are thinner and more flattened, possibly containing blood spots.
- Contain a yolk that may be slightly flattened and enlarged.
- Are given to abnormally misshapen eggs.
- Have an air cell size that must not exceed 3/8 inch in depth.
- Have a shell that must be unbroken and show no adhering dirt.

"C" grades are also given but are not made available to the consumer.

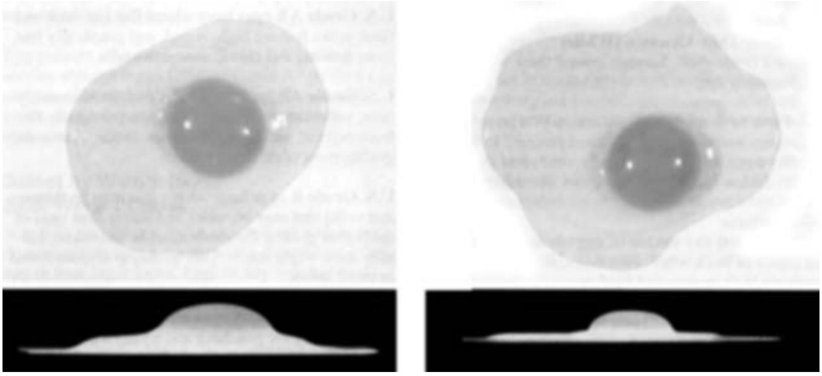


FIGURE 10.6 Quality standards for grades
(*Source*: USDA).

Air Cell

The *air cell*, also known as the *air sac* or *air pocket* (Figure 10.1), is the empty space formed at the large end of the egg. By definition, it holds oxygen. Initially, there either is *no* air cell or a small one. Then it becomes large and apparent to the eye when the warm egg cools, the egg contents shrink, and the *inner* membrane pulls away from the *outer* membrane. The air cell increases in size with *age, cooling, and moisture loss*. It could result in microbial spoilage due to the plentiful oxygen it supplies to microorganisms.

Oftentimes a large air cell is noted as cooled, boiled, *older* eggs are shelled for consumption. Microbial spoilage may follow as oxygen migrates to the yolk; therefore, eggs should be packed with the large, blunt end of the egg *up*. If packed and stored in this manner, air movement from the cell to the yolk is minimized.

According to the American Egg Board, “Although the air cell usually forms in the large end of the egg, it occasionally moves freely toward the uppermost point of the egg as the egg is rotated. It is then called a free or floating air cell. If the main air cell ruptures, resulting in one or more small separate air bubbles floating beneath the main air cell, it is known as a bubbly air cell.”

An acceptable air-cell size for the different grades is contained in the letter grades: 1/8 inch for grade AA, 3/16 inch for grade A, and no limit in air cell size for grade B quality eggs.

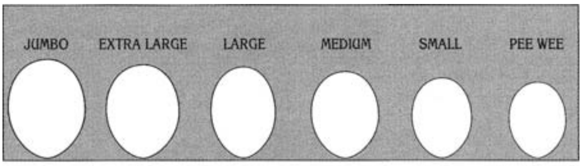
CULINARY ALERT! As a consequence of a large air-cells, older eggs will float if placed in a bowl of water. Floating is an indication of less desirable eggs. The consumer may be familiar with the “floating” test.

Egg Size

Egg-size comparisons are shown in Figure 10.7. The USDA does *not* include an evaluation of egg *size* as a part of egg *quality*. USDA classifications according to size and weight (minimum weight per dozen) as follows:

• Jumbo	30 ounces (4 per cup)
• Extra large	27 ounces
• Large	24 ounces (5 per cup)
• Medium	21 ounces
• Small	18 ounces
• Pee wee	15 ounces

As seen, there is a difference of 3 ounces per dozen between each class. Knowing the ounces in the various sizes assists with pricing. The best value is computed by comparing price *per ounce*. Of course, pricing of *individual* eggs, such a fried egg served for breakfast, may be costed out also. Although undesignated



Minimum wt. per dozen

30 oz.	27 oz.	24 oz.	21 oz.	18 oz.	15 oz.

Minimum wt. per 30 dozen case

56 lbs.	50½ lbs.	45 lbs.	39½ lbs.	34 lbs.	28 lbs.

JUMBO	X-LARGE	LARGE	MEDIUM	SMALL
1	1	1	1	1
2	2	2	2	3
5	5	6	7	8
9	10	12	13	15
18	21	24	27	28
37	44	50	56	62

FIGURE 10.7 Egg sizes
(*Source*: California Egg Commission).

in many recipes for the consumer at home, *large* eggs are the standard size egg used in published recipes.

The major factor in determining egg size is the *age* of the hen; an *older* hen produces a larger egg. Secondary factors influencing size are the *breed* and *weight* of the hen. The quality of the feed, as well as henhouse overcrowding and stress, all impact size, perhaps negatively (USDA).

PROCESSING/PRESERVATION OF EGGS

Treatment involving processing or preservation may occur both for food safety purposes and to keep the egg fresher and limit negative quality changes. Eggs are laid at a hen's body temperature and require subsequent refrigeration. It is possible to hold an egg for 6 months in cold [29–32 °F (0 °C)] storage if the shell pores are closed. Fresh eggs have thick whites and thus do not run when cracked. They contain a very pronounced chalazae cord. Over time, eggs lose moisture and CO_2.

Shell eggs or egg products may be preserved in the following manner.

Mineral Oil

An application of mineral oil is one means of preserving eggs. When oil is applied, it partially closes the shell pores and allows less microorganism permeability. It also allows an egg to hold more moisture, retain their CO_2, and be protected against a pH rise in storage. Shell eggs may be sprayed or dipped in mineral oil on the same day they are laid, and washing off by consumers is unnecessary. Mineral oil dips or sprays may cause a hard cooked egg to be more difficult to peel.

Pasteurization

Pasteurization is a process required by the FDA for all commercial liquid, dry, or frozen egg products that are out of the shell. This treatment destroys microorganisms such as *Salmonella* bacteria that can travel from the digestive tract and droppings of birds into the egg, causing foodborne illness infection. The USDA requires a process of pasteurization that achieves a temperature of 140–143°F (60–62°C), held for 3 1/2 minutes or longer.

The American Egg Board also states "If you bring a food to an internal temperature of 160°F, you will instantly kill almost any bacteria. By diluting eggs with a liquid or sugar (as in custard), you can bring an egg mixture to 160°F."

Pasteurization must allow maintenance of the functional properties of the egg. For example, following pasteurization, egg *whites* can still be whipped for use in a meringue although they need a longer time period to beat to a foam, and *yolks* or *whole eggs* remain functional when used as emulsifiers. Prior to pasteurization, *aluminum sulfate* may be added to egg whites in order to stabilize conalbumin protein that becomes unstable at a pH of 7.0.

Ultrapasteurization of liquid whole eggs combined with aseptic packaging creates a commercial product with numerous advantages over frozen or shell eggs (3, 4). According to a market leader in refrigerated ultrapasteurized liquid whole eggs and scrambled egg mixture, the eggs have a shelf life of 10 weeks when stored between 33 and 40 °F (1–4°C) (5). The eggs are *Salmonella, Listeria,* and *E. coli* negative. The eggs should not be frozen, so that they are not subjected to freezer-to-refrigerator storage, which can result in a loss of functional properties.

Ultrapasteurized liquid whole egg *products* (UPLWEP), developed by a university food science department and foods company (4, 5), were awarded a previous Institute of Food Technologists' Food Technology Industrial Achievement Award. The award recognized UPLWEP as a significant advance in the application of food technology to commercial food production.

Freezing

Freezing is a means of preservation. Since the eggs are broken open they must first be pasteurized prior to freezing. *Uncooked whites* retain their functional properties after freezing and thawing, whereas *cooked* whites exhibit syneresis (water leakage) upon thawing.

Whole eggs and *yolks* may *gel* and become gummy upon thawing as a result of an aggregation of low-density lipoproteins in the yolk. Gumminess is controlled by sugar, corn syrup, or salt addition. Processors may add the enzyme papain in order to hydrolyze the protein. As water is bound to the enzyme, the defrosted product exhibits less gel formation.

CULINARY ALERT! A 10% sugar solution (1 tablespoon of sugar per cup of eggs, household measure), a 5% inclusion of corn syrup, or 3% salt (1 tsp per cup of eggs) may be added to yolks before freezing as a control against aggregation. Choose according to egg usage.

Dehydration

Egg dehydration is a simple process of preservation that began in 1870s. Over the years dehydration has been muchimproved. It offers microbial control to egg products when water levels are reduced by techniques such as spray drying or drying on trays (producing a flaked, granular form). The dehydrated whole egg, white, yolk, or blend is then packaged in various sized packages or drums. Subsequently, it may be reconstituted and cooked or added as an ingredient to packaged foods such as cake mixes or pasta.

Egg *whites* require the removal of glucose prior to dehydration in order to improve storage stability because, otherwise glucose in the whites leads to unacceptable browning and flavor changes. The browning is a result of the Maillard reaction (nonenzymatic) of proteins and sugars in long or hot storage. Glucose may be removed by *Lactobacillus* microbial fermentation or by enzymatic fermentation with commercial enzymes such as glucose oxidase or catalase.

Egg *yolks* undergo irreversible changes in their lipoprotein structure when dehydrated, losing some functional and desirable sensory characteristics. Dried eggs should be kept cold to meet food safety guidelines.

STORING EGGS

In addition to the need for cold storage, other factors are significant in storage. For example, it is recommended that the consumer should store eggs on an *inside* shelf of the refrigerator, large end up, *not* on the door where the temperature is *warmer*. Whether it is 1 dozen eggs or flats of 30 dozen or more, eggs should be kept *in the carton* in which they were obtained in order to prevent moisture loss and the absorption of odors and flavors from other refrigerated ingredients.

CULINARY ALERT! Hard cooked (boiled) eggs may be retained in a refrigerated unit for up to 1 week. Any break-out portions of egg may be safely stored under refrigeration in this manner: yolks in water, for 1–2 days, whites in a covered container for up to 4 days.

The USDA graded eggs are washed, sanitized, oiled, graded, and packaged soon after they are laid, and it is usually a matter of days between the egg leaving the hen house and reaching the supermarket. Cold temperatures, high humidity, and proper handling are required in storage, and when kept cold, eggs may be safely stored for 30 days (4–5 weeks) past the pack date.

According to the American Egg Board, "Egg cartons from USDA-inspected plants must display a Julian date–the date the eggs were packed. Although not required, they may also carry an expiration date beyond which the eggs should not be sold. In USDA-inspected plants, this date cannot exceed 30 days after the pack date. It may be less through choice of the packer or quantity purchaser such as your local supermarket chain. Plants not under USDA inspection are governed by laws of their states." (AEB)

The pack date is stamped on egg cartons as a number of 001 through 365. This number corresponds to the day of the year 1st to 365th, that the eggs were packed. An expiration date of 30 days past the pack date may appear on eggs with the federal grade mark.

DENATURATION AND COAGULATION

Denaturation may be mild or extensive. It occurs when a protein molecule (helical shape) unfolds, changing its nature (thus the word denaturing). This is an *irreversible* change in the specific folding and shape that a protein assumes in space.

Denaturation of the protein in an egg may occur due to *heat, mechanical* action such as beating or whipping, or an *acidic pH*. Regardless of the cause, the helical chains with intramolecular bonds uncoil and align in a parallel fashion, forming intermolecular bonds and the protein chains shrink.

In the *raw* state, eggs appear *translucent* because light is refracted and passed between individual proteins. As the egg denatures, the egg changes in appearance from translucent to *opaque* or *white*. Once *cooked*, light is no longer able to pass between the newly formed protein mass.

Coagulation represents the *further* process that occurs when denatured protein molecules form a solid mass. The liquid/fluid egg (which is a sol) is converted into a solid or semisolid state (which is a gel). Water escapes from the structure as unfolded helixes attach to each other. This coagulation occurs over a wide temperature range and is influenced by factors previously mentioned such as heat, beating, pH, and also use of sugar and salt. Coagulation results in the precipitation of the protein and is usually a desirable characteristic.

Curdling may occur next. Beyond denaturation and coagulation, *undesirable curdling* of egg mixtures results in an egg mixture shrinking or becoming tough. Some factors involved in denaturation, subsequent coagulation, and possible curdling are as follows:

- **Heat**. Heat should be slow and mild. The egg *white* denatures, coagulates, and becomes solid at temperatures of 144–149 °F (62–65 °C). Egg *yolks* begin to coagulate at 149°F (65°C) and become solid at 158°F (70°C). *Whole eggs* coagulate at an intermediate temperature. In the preparation of an egg mixture such as an egg custard, the rate of heating and intensity of heat must be controlled. These characteristics are discussed below.

    - **Rate and coagulation**: A *slow* rate of heating safely coagulates the egg mixture at a lower temperature than a *rapid* rate of heating. A slow rate provides "the margin of error" or *extra time* (for possibly interrupting cooking) between the coagulation temperature and undesirable, fast approaching curdling. A *rapid* rate of heating may quickly exceed the desired temperature and result in undesirable curdling.
    - **Intensity and coagulation**: A *mild* heating intensity denatures and coagulates with desirable molecular associations. As opposed to this, *intense*

  heating applies too much heat, too quickly and causes undesirable curdling with negative changes such as water loss and shrinkage (Chapter 8).
  - **Water bath and coagulation**: Using a water bath controls *both* the rate and intensity of coagulation. It is therefore an advisable baking strategy for baking egg dishes, commercially and at home. The reason it works is that the egg product is placed in an external water medium that cannot exceed the boiling temperature of water!

Other factors influencing the denaturation and coagulation of eggs include the following:

- **Surface changes**. Beating and so forth denatures the helical protein structure. This is readily seen in the white color (explained above) and increased volume of egg white foams used for the preparation of meringues.
- **Acid pH**. An acid pH coagulates egg protein. For example, adding acid to the water used for poaching eggs coagulates the egg white so that it remains small and compact. As well, acid in the cooking water offers control by immediately coagulating undesirable strands of leakage escaping from cracks in eggs that are hard cooked.

CULINARY ALERT! A precaution to note is that acidic cooking water may cause difficulty in peeling an older, more alkaline egg. Thus older eggs, which become alkaline with age, may be cooked in salted water.

EFFECT OF ADDED INGREDIENTS ON COAGULATION

The addition of other ingredients to an egg, such as sugar and salt, affect the denaturation and coagulation process.

Sugar

The addition of sugar exerts a protective effect on the egg by controlling the rate of denaturation and ultimate formation of intermolecular bonds. This is seen in the preparation of meringues. The foam in the meringue will not be as large if sugar is added early, *prior* to denaturation. For larger foams, sugar should be added late, *after* the egg white has denatured.

Sugar also raises the temperature required for coagulation. A custard prepared *with* sugar has a *higher* coagulation temperature than a similar egg–milk mixture *without* sugar but produces no change in the finished gel (Chapter 14)

Salt

When salt is added, it promotes denaturation, coagulation, and gelation. Salt may be a constituent of food, such as the *milk salts* in milk, or it may be *added* to a product formulation. Milk salts contribute to custard gelation, whereas the addition of water to eggs does *not* promote gelation.

Acid Level

As the pH *decreases* and becomes more acidic, coagulation of the egg white occurs more readily. An older, more alkaline egg will result in *less* coagulation than a fresh, neutral pH egg. Vinegar may be added to the water of poached and hard cooked egg to aid in denaturation and coagulation *and* to prevent spreading of egg strands. Coagulation depends on which egg protein is involved and its isoelectric point (pI)—the point at which a protein is least soluble and usually precipitates.

Other Ingredients

Egg is often diluted by the addition of other substances in a food system. The coagulation temperature is *elevated* if an egg mixture is made dilute by water or milk. If a mix is diluted, a less firm finished product results.

COOKING CHANGES

Cooking methods that produce tender, high-quality products should be selected. Some methods include the following.

Pan Frying

- Method: Eggs placed in a preheated pan coagulate the egg proteins.
- Heated pan: Use of a preheated pan allows coagulation before the egg has an opportunity to spread. However, an overheated pan may overcoagulate the egg and produce a tough product.
- Use of fat: Pan frying in a measurable amount of fat and basting the top of the egg with fat produces a tender egg but may not be desirable in terms of the calorie and fat contribution that is offered (Figure 10.8)

CULINARY ALERT! Eggs may be pan "fried" in liquids other than fat or oil and the pan lid may remain in use to create steam that cooks the egg.

Hard Cooked Eggs

"Hard boiled" is another, less appropriate term for these eggs. However, boiling the eggs is not desirable.

- Method: It is recommended that eggs be placed one layer deep in a covered saucepan of boiling water and then simmered, not boiled, for 15–18 minutes for a hard cooked egg or just 2-1/2–5 minutes for a soft "boiled" egg. More than one layer deep or placing eggs in cold water at the start of cooking may retard the "doneness" of hard cooked eggs.
- Peeling: Eggs should be cooled *rapidly* to facilitate easier peeling. Fresh eggs may be difficult to peel, in part because an alkaline pH has not yet been achieved.

FIGURE 10.8 Pan fried eggs.

- Cracking: In order to prevent cracking from an expansion of air in the air cell and the build up of internal pressure, it may be recommended that the egg be punctured at the large end. However, this seemingly logical step has *not* been shown to prevent cracking of the shell. For prevention, the egg may be warmed slightly prior to cooking.
- Color: Green discoloration of hard cooked eggs occurs with long and high heat exposure. The green color is due to the formation of *ferrous sulfide* from *sulfur* in the egg white protein combining with *iron* from the yolk. "Greenish yolks can best be avoided by using the proper cooking time and temperature and by rapidly cooling the cooked eggs." (AEB).

CULINARY ALERT! Hard *cooked* is the term of choice when referring to "hard*boiled* eggs." Eggs are tenderer when they reach a simmering, not boiling, temperature.

Custard

- Method: Custards (served plain or incorporated into cream desserts, flan, or quiche) are cooked with a *slow rate* of heating. This provides a margin of error that protects against a rapid temperature elevation from the point of coagulation to undesirable curdling where the protein structure shrinks and releases water. Custards cooked with the addition of a starch white sauce are able to withstand higher heat because starch exerts a protective effect on the denatured proteins.
- *Stirred* custard: Custards may be stirred or baked. Soft, *stirred* custard will cling to a stirring spoon as it thickens. It remains pourable and does not form

a gel. If overheated or heated too quickly, the mixture curdles and separates into curds and whey. Therefore, the use of a double boiler is recommended in order to control temperature and the rate of cooking. As mentioned, starch may be added to the formulation in order to prevent curdling.

- *Baked* custard reaches a *higher* temperature than stirred custard and gels. Baking in a *water bath* is recommended in order to control the rate and intensity of heat and prevent the mixture from burning. With the addition of starch in a recipe, this is not required. Cooking/holding for an extended period of time, even in a water bath could cause syneresis (Figure 10.9).
- Texture: The texture of an egg custard is dependent on a number of factors, including the extent of egg coagulation and added ingredients. A well-coagulated custard is fine textured; a curdled custard is extremely porous, tough, and watery.

CULINARY ALERT! Milk assists in coagulating the egg; sugar raises the coagulation temperature, and custards prepared with starch (such as arrowroot, cornstarch, flour, tapioca) control curdling.

CULINARY ALERT! Of course, cooking with a double boiler or water bath where applicable, always helps, as if regulates temperature.

Scrambled Eggs

- Method: Cook with short cooking, at medium high.

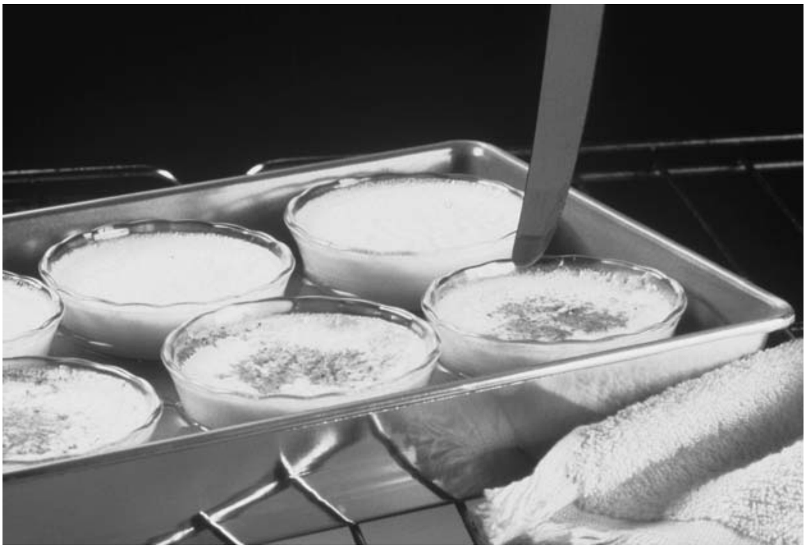


FIGURE 10.9 Custard baked in water bath (*Source*: American Egg Board).

- Dilution: This may result in less solid coagulation.
- Discoloration: Negative coloring may appear in eggs as ferrous sulfide forms. Avoid direct heat when holding eggs. Water may be placed between the pan of eggs and the source of heat.

EGG WHITE FOAMS AND MERINGUES

The egg white foam is created as the liquid egg whites are *beaten or whipped* to incorporate air. The egg white volume expands with beating as the protein denatures and coagulates around the many newly formed air cells.

The beaten whites are used in numerous food applications, as meringues, or incorporated into a recipe to lighten the structure. The volume and stability of egg white foams is dependent on conditions such as the humidity in the air, temperature of the egg, and other added substances, as shown in Table 10.4.

CULINARY ALERT! Care should be taken to gently *fold*, not *stir* the beaten egg white foam into the other recipe ingredients. After all, it was work to create the foam, and the air cells should not be roughly treated (see Figure 10.10)

A variety of food products are created using egg white foams, including cakes, dessert shells, sweet or savory soufflés, and pies. A sweet egg white foam is known as a meringue and may be either soft or hard, the latter prepared with more sugar. Examples of sweet meringue confections include pies, cookies, and candies.

The majority of meringues require that egg whites be beaten to either the soft or stiff peak stage, and then immediately added to the recipe. Processors use egg white foams to create special appearance and volume for their products.

CULINARY ALERT! Use *superfine* sugar for glossy meringues. Otherwise ordinary *granulated* sugar may be incorporated if it is first processed in the food processor for 1 minute.

Possible errors arise if the foam is *not immediately* incorporated into a formulation or if eggs are *overbeaten*. When not incorporated immediately, the recipe may lose some of its characteristic elasticity, and upon standing become stiff and brittle. If overbeaten, the foam is not able to expand with heat since the eggs become inelastic.

An additional error results from using cold eggs. They have a high surface tension and do not beat to as high a volume as room temperature eggs. It is recommended to allow eggs to reach room temperature for better whipping, yet this practice carries with it the increased risk of *Salmonella* growth.

TABLE 10.4 Beaten Egg White Foam

Stage	Description
Unbeaten raw egg white	• small volume of thick and thin whites • no initial additives
Foamy	• unstable, large air-cell volume, transparent • bubbles coalesce if beating is halted • acid coagulates protein around air cell • add cream of tartar (acid) now
Soft, rounded peaks	• air cells subdivide in size and are whiter • volume is increased • add sugar now • may be used for food applications • used for soft meringue
Stiff, pointed peaks	• many small air cells, volume is increased • egg protein coagulates around fine air cells • ready for most food applications • used for hard meringue
Dry peak foam	• brittle, inelastic; less volume as air cells break • denatured, water escapes, ***flocculated*** • not as effective as a leavening agent • overcoagulated, curdled appearance

CULINARY ALERT! Rather than setting eggs out to warm to room temperature, egg whites may be slightly warmed by placing the appropriate number of whites in a bowl which is then set in another bowl of warm water. This allows the egg whites to warm up prior to whipping.

Leavening is diminished if *older* eggs are used for creation of foams. While older eggs whip up more easily than fresh eggs, protein does not coagulate well around the air cells and there is a higher percentage of thin whites that create large, unstable foams.

Egg yolks contain fat that physically interferes with the alignment of protein around air cells. Therefore, the yolks should be *completely* separated from the whites, not allowing *stray* yolk to enter the white in separation. Separation works easier when eggs are cold. Although egg yolks cannot form foams, they may be beaten to become thicker. They may be used in other cooking applications

FIGURE 10.10 Unbeaten (top) and beaten egg whites (bottom) after addition of acid and sugar
(*Source*: American Egg Board).

It is common practice to separate the yolk and white by using the two broken halves of the shell. Repeatedly passing the egg contents from one shell to the other, releases the white (perhaps into a bowl), and retains the yolk.

The American Egg Board offers information about separating eggs. "Bacteria are so very tiny that, even after washing and sanitizing, it's possible that some bacteria may remain in the shell's pores. The shell might also become contaminated from other sources. When you break or separate eggs, it's best to avoid mixing the yolks and whites with the shells. Rather than broken shell halves or your hands, use an inexpensive egg separator or a funnel when you separate eggs to help prevent

TABLE 10.5 Some Factors Affecting the Volume and Stability of Egg White Foams

Temperature—The temperature of eggs influences beating ability. At room temperature, eggs have less surface tension and are more easily beaten than if they were cold. Yet, at warm temperatures, *Salmonella* may grow and cause illness in susceptible individuals.

pH—Acid should be added in the whipping process *after* eggs reach the foamy stage and have large air cells. If acid substances such as cream of tartar are added to raw egg whites at the *beginning* of the beating process, there is less volume but greater stability due to intramolecular bond coagulation.

Salt—Salt adds flavor. Its presence delays foam formation, and if added early in the beating process, produces a drier foam with less volume and stability. Salt should be added to egg white foams at the foamy stage or later if flavor is needed.

Sugar—The protective effect of sugar on eggs has been discussed.

- Early Addition The early addition of sugar causes less intermolecular bonding of the egg proteins than would occur in the absence of sugar. Therefore, the addition of sugar results in an egg foam that is stable but has less volume. A fine-textured, more stable foam develops if finely ground sugar is added *early* in the beating process.
- Late Addition Sugar (2–4 tablespoons per egg white, respectively, for soft or hard meringues) should be added to foams gradually, at the soft peak or stiff peak stage of development, *after* large air cells have formed and denaturation has begun. On a damp day, the preparation area may contain a lot of humidity that is absorbed by the sugar and this results in a softer meringue (hydroscopicity Chapter 14).

Fat—Traces of fat may remain in the equipment used for beating egg white foams, it may originate from the egg yolk, or it may be introduced by another added ingredient in the product formulation. If fat enters the egg white, there will be substantially less foaming and less volume. Fat interferes with the foaming that would occur if protein aligned itself around the air cell and coagulated.

Liquid—The addition of liquid dilutes the egg white. A benefit is that added liquid, such as water, will increase volume and tenderness of foams, yet it results in a less stable, softer foam and an increased likelihood of syneresis. Dried egg white that has been reconstituted with a liquid require longer beating time than fresh egg whites, due to some protein breakdown in the drying process.

Starch—Starch assists in controlling coagulation in proteins and is of benefit to soft meringues. A starch should first be cooked and then incorporated into the meringue.

introducing bacteria. Also use a clean utensil to remove any bits of eggshell that fall into an egg mixture and avoid using eggshells to measure other foods."

Commercial egg *substitutes* may be successfully used in the preparation of foams since they consist primarily of whites and contain no fat. They are similar to shell egg whites, aside from imparting the yellowish color (see also Table 10.5).

Another point to address in egg meringues is the use of copper bowls. Copper bowl usage for beating egg whites has been a recommendation over the years. It turns out that conalbumin protein combines with traces of copper from the bowl, producing *copperconalbumin*. There is no noticeable effect in the *unbaked* foam; however, the result is significant leavening in the *baked* product. Due to toxicity issues, the use of copper bowls is no longer recommended.

Hard meringues may be a key ingredient of some cookies or candy. Soft meringues are used most notably on pie. The special problems that may arise with soft meringues are shrinking, weeping, and beading. A hot oven and cold pie filling may be responsible for these problems in the same meringue.

Weeping is the release of water from *under* coagulated (perhaps underbeaten or undercooked) egg white foam. A release of water at the interface of the meringue and filling may form a water layer causing the meringue to slide off. This occurs if the meringue is placed on a *cold* filling.

Therefore, to prevent weeping, prepare the meringue first and then the already-prepared meringue may be placed on a *hot* filling and *immediately* baked. Both the filling and the oven should be hot. Another method used for control is the addition of $1/2$ to 1 teaspoon of cornstarch to the sugar prior to beating it into the eggs.

Beading is apparent in *over*coagulated (overcooked) meringues. Beading appears as drops of amber-colored syrup on top of meringue. It may be the result of (1) adding too much sugar or the insufficient incorporation of the sugar into the beaten egg whites. It also may be the result of (2) baking too long, at a low temperature. For control, a high temperature for a short time is needed.

CULINARY ALERT! Placing one layer of meringue at a time, after the previous layer adheres to the filling, is helpful. As well, a fine layer of breadcrumbs may be sprinkled on the hot filling prior topping with the meringue.

A brief look at the stages of denaturation when egg whites are beaten to foam appears in Table 10.4.

CULINARY ALERT! Slicing a gummy, sticky, beading meringue surface requires use of a sharp serrated knife dipped in cold water prior to each slice.

EGG PRODUCTS AND EGG SUBSTITUTES

Egg products include pasteurized, processed, refrigerated liquid, frozen, and dried eggs that are available in the marketplace to commercial and retail users. If in liquid form, eggs may be ultrapasteurized or aseptically packaged (see Chapter 11, or see Packaging of Food Products in Chapter 19) to extend shelf life. Egg substitutes have *no* yolks and may contain 80% egg white. Generally, the "yolk" is made of corn oil, nonfat milk solids (NFMS), calcium caseinate, soy protein isolate, soybean oil, and other substances, including vitamins and minerals. The egg substitute also contains no cholesterol, less fat, and more unsaturated fat than whole egg. Many US egg patents have been issued relating to low-fat and low or decholesterized egg products (6, 7).

The use of egg substitutes in scrambled eggs and omelets requires an equipment surface cooking temperature of 250–280 °F (121–138 °C), well below the typical restaurant griddle temperature of 350–375 °F (177–191 °C). Use of an omelet pan or aluminum pan on the griddle reduces the temperature of the pan interior to an appropriate level without turning down the griddle (5).

CULINARY ALERT! Egg substitutes although yellowish in color may be beaten for use in foams.

NUTRITIVE VALUE OF EGGS

Eggs contain vitamins A, D, E, the water-soluble Bs, and minerals such as iron, phosphorus, and zinc as well as iodine, potassium, and sulfur. They are low in calories—75 calories per large egg—and are used to fortify other foods that are low in protein.

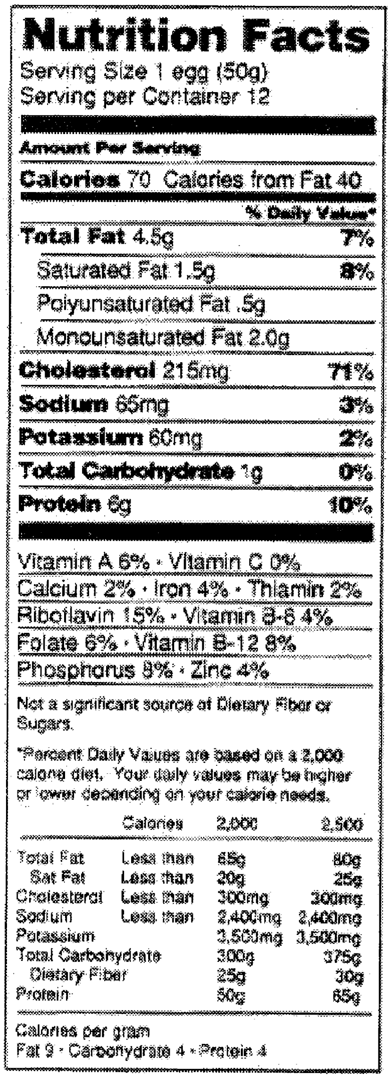
Eggs are a complete protein, with a biological value of 100, which indicates that all of the protein is retained by the body. All other protein sources are evaluated against this standard. That is not to say that eggs are “the perfect food.” Persons following a vegetarian diet may include eggs in their diet for meeting essential protein requirements. If so, a person is then an ovovegetarian.

Egg whites are given the highest protein-digestibility-corrected amino acid score (PDCAAS) of 1.0, which corrects the amino acid composition with its digestibility. For FDA labeling purposes, the PDCAAS method of determining protein quality is used. The “% Daily Value” for protein that appears on labels reflects both the quantity (in grams) and quality of protein (Table 10.6).

Egg yolks contain cholesterol, which must be restricted by some individuals, and over the past years the American Heart Association has changed its recommendations to eating four eggs per week. Technology has made the determination of cholesterol content more accurate and reflective of the actual amount and has produced eggs that are lower than the USDA analysis of 215 mg cholesterol which is calculated for the majority of eggs. These developments may be achieved by control of animal feed, without using drugs, hormones, or antibiotics. Additional data on dietary cholesterol and its effect on lipoprotein metabolism are reported in (6–8). The Egg Nutrition Center site is for anyone who wants to learn

TABLE 10.6 Protein-Digestibility-Corrected Amino Acid Score of Selected Foods

Egg white	1	Chick peas	0.66
Casein (milk)	1	Pinto beans	0.63
Soybean isolate	0.99	Rolled oats	0.57
Beef	0.92	Lentils	0.52
Kidney beans	0.68	Whole wheat	0.40



Nutrition Facts

Serving Size 1 egg (50g)
Serving per Container 12

Amount Per Serving

Calories 70 Calories from Fat 40

	% Daily Value*
Total Fat 4.5g	**7%**
Saturated Fat 1.5g	**8%**
Polyunsaturated Fat .5g	
Monounsaturated Fat 2.0g	
Cholesterol 215mg	**71%**
Sodium 65mg	**3%**
Potassium 60mg	**2%**
Total Carbohydrate 1g	**0%**
Protein 6g	**10%**

Vitamin A 6% · Vitamin C 0%
Calcium 2% · Iron 4% · Thiamin 2%
Riboflavin 15% · Vitamin B-6 4%
Folate 6% · Vitamin B-12 8%
Phosphorus 8% · Zinc 4%

Not a significant source of Dietary Fiber or Sugars.

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Potassium		3,500mg	3,500mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g
Protein		50g	65g

Calories per gram
Fat 9 · Carbohydrate 4 · Protein 4

about eggs and good nutrition: http://www.enc-online.org. A carton nutrition facts label for eggs:

SAFETY OF EGGS

A product warning related to eggs is on egg labels: "Safe Handling Instructions: To prevent illness from bacteria: keep eggs refrigerated, cook eggs until yolks are firm, and cook foods containing eggs thoroughly." The contents of freshly laid eggs are generally sterile, although *Salmonella enteritidis* (SE) has been found inside some eggs. Eggs are *usually* protected from bacteria by the shell and the two shell membranes; however, the surface of shell eggs may contain a high level of bacteria. These bacteria may enter the shell through the pores, especially when it is soiled and washed. If bacteria travel to the internal portion of the egg, it is typically the egg yolk membrane (ie, the vitellin membrane), *not* the yolk or white that harbors the bacteria.

According to the American Egg Board, ”. . . protective barriers include the shell and yolk membranes and layers of the white which fight bacteria in several ways. The structure of the shell membranes helps prevent the passage of bacteria. The shell membranes also contain *lysozyme*, a substance that helps prevent bacterial infection. The yolk membrane separates the nutrient-rich yolk from the white.”

The Egg Safety Action Plan, a joint effort by the FDA and USDA, was announced in late 1999. Its intent was to reduce the incidence of SE, and it contains two important requirements:

- The refrigeration requirement in this plan is that eggs delivered to a retail establishment (restaurants, hospitals, schools, nursing homes grocery stores, delis, and vending operations) must be quickly stored at an ambient temperature of 45 °F (7 °C) or less upon receipt.
- There is a required statement on shell-egg cartons that reads as follows:

According to the FDA raw eggs should not be used, especially by population groups such as the young, elderly, or immune compromised.

In November, 2000, the FDA Commissioner, Dr. Jane Henney, added “. . . no sunny side up, no over easy”

The FDA prohibits the use of raw or lightly cooked eggs in food production or manufacturing facilities. Eggs must reach an internal temperature of 145°F (63°C) or higher to be considered safe for consumption (check local jurisdiction). Egg products must be pasteurized.

As well, the President’s Council on Food Safety has encouraged developments in science and technology by companies and universities to reduce the incidence of SE. For example, methods are being investigated/employed to bring an egg temperature down form 109°F (43°C) (the internal temperature of hens) to a cold temperature of 45°F (7°C) to control SE. One such method utilizes cryogenic carbon dioxide; another uses a clean warm-water bath to kill bacteria without cooking (10, 11).

International contamination of eggs with SE is very low, even from a known positive flock (9). Yet, the safety of eggs must be ensured. For example, only clean, uncracked eggs should be purchased from a reputable supplier. Exterior surface bacteria can enter shells of dirty eggs or even clean ones, especially through cracks causing the egg to be unsafe. Also, since washing is a routine step in commercial egg processing, rewashing eggs prior to use is not necessary or recommended. When eggs are washed in warm water and then refrigerated, pressure changes in a cooling egg draw harmful exterior microbes in through the pores. Eggs should be stored cold at temperatures of approximately 40°F (4.4°C).

CULINARY ALERT! One more safety consideration involves the common restaurant practice of "pooling" (commingling). Pooled eggs involve many eggs cracked together and stored ahead, ready to use. As a result of pooling, contamination likelihood is increased.

Prior to incorporation into recipes, either egg yolks or the egg white to be used for meringue may be heated over direct heat or water bath to raise the temperature while controlling SE. If the egg is refrigerated, bacterial growth is extremely slow and disease is not likely to result. Egg products are pasteurized and free of *Salmonella*.

Hard-cooked eggs reach a final cooking temperature that is sufficient to kill the natural bacteria of an egg, yet *recontamination* may occur. For example, recontamination may be due to the practice of "hiding Easter eggs" wherein the oil coating of the egg may be lost and the pores of the egg may open. Subsequently, the egg may be contaminated with substances such as lawn chemicals, fertilizers, or droppings from household pets, birds, reptiles, and rodents (7). Thus, for consumers who follow the traditional practices of decorating and hiding Easter eggs, the USDA caution remains: Keep perishables at room temperature for no longer than 2 hours. Decorated eggs are festive and may be very inexpensive, and thus are included in many celebrations, but the recommendation is that separate eggs be used for eating and decorating or "hiding."

Egg White Resistance to Bacterial Growth

Egg whites have natural protection against microorganisms by several natural *chemical components*; however, they cannot be considered 100% safe once the shell has been broken or cracked. These components include *avidin, lysozyme,* and *conalbumin*. *Avidin* in the raw egg white binds the vitamin biotin required for some microorganism growth. Lysozyme hydrolyzes cell walls of some bacteria, and thus demonstrates antibacterial action, especially at lower pH levels. *Conalbumin* binds with the iron of the yolk preventing growth of the microorganisms that require iron for growth.

Pasteurized raw eggs in uncooked foods such as mayonnaise do not support the growth of bacteria as do unpasteurized shell eggs. Thus, only pasteurized egg products may be used in manufacturing or retail operations, where a food containing eggs is not subject to adequate heat treatment. Uncooked meringues prepared by shell egg whites that are not pasteurized are considered a "low-risk" food, though, because they contain a large amount of sugar that ties up the water needed for bacterial growth. The water activity needs of the bacteria are not met and the bacteria do not grow.

CULINARY ALERT! Some risk of bacterial presence remains and it is recommended that all raw egg parts, including egg whites, be cooked prior to use (Chapter 16).

"In addition to containing antibacterial compounds such as lysozyme, layers of the white discourage bacterial growth because they are alkaline, bind nutrients bacteria need and/or don't provide nutrients in a form that bacteria can use. The thick white discourages the movement of bacteria. The last layer of white is composed of thick ropey strands which have little of the water that bacteria need but a high concentration of the white's protective materials. This layer holds the yolk centered in the egg where it receives the maximum protection from all the other layers." (AEB)

USDA Sampling

The USDA-administered Egg Products Inspection Act of 1970 requires routine sampling and analysis and routine inspection for wholesome, unadulterated eggs and egg products. Plants are inspected regardless of whether the shipment is intrastate, interstate, or out of the country. State standards, regulated by the state's Department of Agriculture must be equivalent to federal standards.

CONCLUSION

Whole eggs and their component parts are important for their array of functional properties such as binding, emulsification, foaming, gelling, and thickening. These properties change with cooking as the egg protein denatures. The processes of grading and evaluation of quality, although not mandatory, are officially carried out by the USDA and their state counterparts.

Eggs are candled in order to evaluate and assign grades. In candling, the yolk, white, and air-cell size as well as the integrity of the shell are viewed prior to sale. Egg size is not a part of egg quality evaluation. The color of a shell is dependent on the breed of hen and the yolk color is dependent on the feed.

Processing and preservation of eggs occurs with the use of mineral oil and the techniques of pasteurization, freezing, and dehydration, after which proper storage is important in maintaining safety and other aspects of food quality. The addition of other ingredients to an egg, such as salt and acid, promote denaturation. Sugar exerts a protective effect, controlling the denaturation and coagulation processes. Some factors affecting the volume and stability of egg white foams include temperature, pH, salt, sugar, fat, and addition of liquid. The recommendation is that eggs not be old or cold.

Various forms of eggs, including pasteurized shelled eggs, are available and egg substitutes may be purchased in the marketplace. Eggs have a biological value of 100 and are given the highest PDCAAS score. Vigilance is necessary in the handling and use of eggs, a potentially hazardous food.

GLOSSARY

Air cell or air pocket: A space between shell membranes where air is found within the shell, typically at the large end of an egg.

Biological value: Eggs contain a score of 100 based on its efficiency in supporting the body's needs; reflects the amount of nitrogen retained in the body, due to the completeness of the protein. (An incomplete protein is deaminated and nitrogen is not retained.)
Beading: Amber-colored syrup beads on top of baked meringue as a result of overcoagulation.
Binder: Holds the ingredients of a mixture or its breading together.
Candling: Viewing the inside and shell of an egg by holding it up to a bright light.
Clarify: To remove foreign particles from a hot liquid.
Coagulation: Extensive denaturation of protein molecules yielding a solid mass or gel.
Curdling: The protein precipitates, shrinks, releases water, and becomes tough.
Denaturation: Changes in the conformation of a protein caused by changes in temperature, an acidic pH, or by surface changes such as mechanical beating.
Egg substitute: Liquid or frozen egg white product with a "yolk" typically consisting of corn oil, nonfat milk solids, calcium caseinate, soy protein isolate, soybean oil, and other substances.
Emulsifier: Material that allows two ordinarily immiscible substances to mix.
Flocculated: Separation of overbeaten egg white foam into small masses.
Foam: Increased volume of beaten egg white that holds shape as protein coagulates around air cells.
Gel: A two-phase system where egg coagulates with liquid in a solid.
Pasteurization: Heating for a specific time at a temperature that eliminates pathogens.
Protein-digestibility-corrected amino acid score (PDCAAS): A measure of protein quality that compares the amino acid balance with requirements of preschoolers and corrects for digestibility. Used by the FDA for labeling and by the WHO.
***Salmonella enteritidis* (SE)**: Pathogenic, infection-causing bacteria especially prevalent in poultry and eggs.
Syneresis: "Weeping" or water leakage from coagulated egg.
Thickening agent: Increases viscosity.
Ultrapasteurization: High-temperature, short-time heat to kill pathogenic microorganisms.
Weeping: Syneresis or release of water from undercoagulated or underbeaten egg whites.

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CHAPTER 11

Milk and Milk Products

INTRODUCTION

Milk is the first food of young mammals produced by the mammary glands of female mammals. It is a mixture of fat and high-quality protein in water and contains some carbohydrate (lactose), vitamins, and minerals. Milk and milk products may be obtained from different species, such as goats and sheep, but the focus of this chapter is on *cow* milk and milk products.

While fluid milk contains a very large percentage of water, it may be concentrated to form evaporated milk and cheeses. Throughout the world, it is used in a variety of ways, such as a beverage, cheese, yogurt, or in soups and sauces.

By law, milk and milk products must contain a designated percent of ***total milk solids*** (all of the components of milk except water) and also the ***milk solids, not fat*** (***MSNF***) (all of the components of milk solids not including fat). The butterfat component of milk is the most expensive component of milk and its level determines if milk is offered for retail sale as whole milk or at some lesser percentage of fat, such as 2% milk, 1%, 1/2%, or fat-free.

Milk may be cultured, dried, fortified, homogenized, or pasteurized and used to create products with different taste, texture, nutritive value, and shelf life. It may be processed into products such as buttermilk, cheese, cream, ice milk, ice cream, sour cream, and yogurt with different levels of fat content. Dried milk is added to a multitude of foods. It may be added to foods to increase the protein or calcium value.

High temperatures may curdle milk; therefore, care must be taken in the preparation of foods with milk. Milk requires safe handling and cold storage.

Milk is not well tolerated by a large portion of the population. The milk sugar, lactose, is not digested by persons lacking the enzyme lactase.

DEFINITION

"Milk means the lacteal secretion, practically free from colostrum, obtained by the complete milking of one or more healthy cows, which may be clarified and may be adjusted by separating part of the fat there from; concentrated milk, reconstituted milk, and dry whole milk. Water, in a sufficient quantity to reconstitute concentrated and dry forms, may be added." Other useful FDA definitions appear throughout this chapter (FDA).

COMPOSITION OF MILK

Milk varies in physical and chemical composition depending on such factors as age and breed of the cow, activity-level, stage of lactation, use of medication, and interval between milking. It consists mainly of water and contains some serum solids or milk solids-not-fat (MSNF) such as lactose, caseins, whey proteins, and minerals. Milk also naturally contains fat.

Water

Milk is composed *primarily of water*, which is present at a level of approximately 87–88%. If that water is removed, the shelf life of milk products is greatly extended.

Carbohydrate

Carbohydrate is water-soluble and present in the aqueous phase of milk, at levels of approximately 5%. The disaccharide *lactose* is the main carbohydrate. It exhibits low solubility and may precipitate out of solution as a grainy textured substance. It is converted to lactic acid (1) upon souring due to bacterial fermentation, and (2) in the process of aging cheese. Therefore, aged cheese may be digestible by lactose-intolerant individuals even in the absence of the enzyme lactase. (The lactose content of milk and some milk products appears in Table 11.2. See Lactose Intolerance)

Fat

Fat has a low density and *easily* may be centrifuged or *skimmed-off* of the milk yielding low-fat or *skim milk*. The fat, or butterfat, exists at levels of 3–4% in whole milk (varying by state law), at lesser levels in reduced-fat milks, and at *significantly* higher percentages in cream. Fat is the expensive component of milk and the basis on which dairy farmers are paid for milk. When fat and its carotenoids are removed, milk is bluish in color.

Fat globules are less dense than the water in the aqueous phase of milk, and therefore, rise to the top of the container in the ***creaming*** process. When emulsified during *homogenization* there is an increase in the number of fat cells and greater viscosity because the fat is distributed throughout the fluid and creaming does *not* occur. Membranes of lipids and protein, including lecithin, from each fat globule remain in the milk as it is processed.

Fat content in milk varies greatly in calories. The completeness of milking determines richness of the fat content. Milk either carries or may be fortified to contain the fat-soluble vitamins, and it contains the pigments carotene and xanthophyll. Fat contains the sterol cholesterol and phospholipids, but it is primarily triglyceride (95%) with saturated, polyunsaturated, and monounsaturated fatty acid components. These have varying melting points and susceptibility to oxidation. The fatty acid chains contain many short-chain fatty acids such as the saturated butyric acid (4° C) and caproic, caprylic, and capric acids.

"Nonfat milk means skim milk, concentrated skim milk, reconstituted skim milk, and nonfat dry milk. Water, in a sufficient quantity to reconstitute concentrated and dry forms, may be added" (FDA).

Protein

Protein represents 3–4% of the composition of milk and components may be fractioned out of milk by *ultracentrifugation*. ***Casein is the primary protein of milk***, comprising approximately 80% of the milk protein. The caseins are actually a group of similar proteins, which can be separated from the other milk proteins by acidification to a pH of 4.6 (the isoelectric point). At this pH, the caseins aggregate, since they are hydrophobic, are poorly hydrated, and carry no net charge. The other milk proteins, being more hydrophilic, remain dispersed in the aqueous phase.

There are three main casein fractions, known as alpha$_s$-, beta-, and kappa-casein (α_s-, β-, and κ-casein). Alpha$_s$-casein actually comprises two fractions: α_{s1}-casein and α_{s2}-casein. However, these two fractions are difficult to separate from each other. The four fractions α_{s1}-, β-, κ-, and α_{s2}-casein occur in the weight ratio 3:3:1:0.8. All four fractions are phosphoproteins containing phosphate groups esterified to the amino acid serine. The α_s- and β-casein fractions contain several phosphate groups and as a result are "calcium-sensitive" and may be coagulated by addition of calcium. Kappa-casein contains only one phosphate group and is not calcium sensitive. The α_s- and β-casein fractions are very hydrophobic. However, κ-casein is a glycoprotein containing an acidic (charged) carbohydrate section, and so it is much more hydrophilic.

In milk, the casein fractions associate with each other and with colloidal calcium phosphate to form stable spherical structures known as ***casein micelles***. The more hydrophobic α_s- and β-casein fractions exist mainly in the interior of the micelles, whereas the more hydrophilic κ-casein exists mainly on the micelle surface. It is the κ-casein that gives the micelles their stability in milk under normal handling conditions. This is due to the negative charge and hydration of the kappa-casein, coupled with the fact that the charged hydrophilic carbohydrate section of the molecule tends to protrude from the micelle surface in hair-like structures, which confer steric (or spatial) stability on the micelles.

The casein micelles are *coagulated by addition of acid* at a pH of 4.6–5.2. As the micelles approach their isoelectric point, the charge and extent of hydration is reduced, and the k-casein hairlike structures flatten, reducing steric hindrance. Hence, the micelles are no longer stable and so they aggregate. This is the basis for the formation of cottage cheese, which is an acid cheese containing casein curds. Acid also causes some calcium to be removed from the micelles, and so cottage cheese is relatively low in calcium compared with some other dairy products.

The casein micelles also may be *coagulated by addition of the enzyme* ***rennin***, which may be added to milk to prepare rennet custard or cheese. Rennin cleaves a specific bond in k-casein and causes the charged, hydrophilic hairlike structures to be removed from the micelles. As a result, the micelle surface is uncharged, hydrophobic, and unstable, and so the micelles aggregate to form curds. The curds may be separated from the whey and processed to form cheese (see section on Cheese). Coagulation by rennin does not cause calcium to be removed from the micelles.

Casein micelles are relatively heat stable and are not denatured by heat (at neutral pH) unless temperatures are very high and heating is prolonged. This is not a problem under most cooking conditions. However, it is a potential problem in heated concentrated milk products such as evaporated milk. The problem is avoided by addition of carrageenan to protect the protein.

Caseins contain both hydrophobic and hydrophilic sections; in addition, they contain a high proportion of the amino acid proline, and so they are flexible proteins containing little regular, ordered secondary structure (see Chapter 8). As a result, they readily adsorb at an oil–water interface, forming a stable film which prevents coalescence of emulsion droplets (see Chapter 13); thus they make excellent emulsifiers.

A *second protein fraction* of milk is the whey or serum. It makes up approximately 20% of milk protein and includes the *lactalbumins* and *lactoglobulins*. Whey proteins are more hydrated than casein and are denatured and precipitated by heat rather than by acid. (More information is contained in this chapter in the section entitled Whey.)

Other protein components of milk include enzymes such as lipase, protease, and *alkaline phosphatase*, which hydrolyze triglycerides, proteins, and phosphate esters, respectively. The average measures of protein quality, including biological value, digestibility, net protein utilization, protein efficiency, and chemical score, for milk and milk products appear in Table 11.1.

Vitamins and Minerals

Milk contains both water-soluble and fat-soluble vitamins. The nonfat portion of milk is especially plentiful in the B vitamin riboflavin, a greenish fluorescent-colored vitamin. It acts as a photosynthesizer and is readily destroyed upon exposure to sunlight.

Vitamin A is *naturally* in the fat component of *whole* milk and more may be added prior to sale. However, whole milk is generally (98%) *fortified* with

TABLE 11.1 Average Measures of Protein Quality for Milk and Milk Products

	BV	Digestibility	NPU	PER[a]	Chemical Score
Milk	84.5	96.9	81.6	3.09	60
Casein	79.7	96.3	72.1	2.86	58
Lactalbumin	82	97	79.5[b]	3.43	c
Nonfat dry milk	–	–	–	3.11	–

Note: Biological value (BV) is the proportion of absorbed protein that is retained. *Digestibility* (D) is the proportion of food protein that is absorbed. *Net protein utilization* (NPU) is the proportion of food protein intake that is retained (calculated as BV × D). *Protein efficiency ratio* (PER) is the gain in body weight divided by weight of protein consumed. *Chemical score* is the content of the most limiting amino acid expressed as a percentage of the content of the same amino acid in egg protein.

[a] Often PER values are adjusted relative to casein which may be given a value of 2.5.

[b] Calculated.

[c] Denotes no value compiled in Food and Agriculture Organization of the United Nations (FAO) report.

Source: Adapted from the National Dairy Council.

vitamin D because it is naturally present only in *small* amounts. Vitamin D is present in milk to some extent due to the synthesis of vitamin D by the cow as it is exposed to sunlight and because vitamin D may be present in animal feed. *Low-fat* and *nonfat* milk are fortified with *both* of these fat-soluble vitamins because milk fat is reduced or absent.

Minerals such as calcium and phosphorus are present at levels of approximately 1% of milk, with a third of calcium in solution and twothirds of it colloidally dispersed. Calcium is combined with the protein casein as calcium caseinate, with phosphorus as calcium phosphate and as calcium citrate. Other minerals present in milk are chloride, magnesium, potassium, sodium, and sulfur.

Classification of Milk

Whole milk may be classified as a solution, dispersion, or emulsion as follows:

- *Solution*: contains the sugar lactose, the water-soluble vitamins thiamin and riboflavin, and many mineral salts such calcium phosphate, citrates, and the minerals chloride, magnesium, potassium, and sodium
- Colloidal *dispersion* (sol): casein and whey proteins, calcium phosphate, magnesium phosphate, and citrates
- *Emulsion*: fat globules suspended in the aqueous phase (serum) of milk. The fat globules are surrounded by a complex membrane, the milk fat globule membrane, which contains mainly protein and phospholipids (and a few carbohydrate side chains at the outer surface). This membrane prevents coalescence of the fat droplets.

SANITATION AND GRADING OF MILK

Milk is a *potentially hazardous food* that must be kept *out* of the temperature danger zone. With its high water content and plentiful protein, vitamins, and minerals, milk is an ideal medium for supporting bacterial growth. Production, processing, and distribution of milk must ensure that products are kept *free* from pathogenic bacteria and low in nonpathogens. *Healthy cows* and *sanitary* conditions of handling lead to *low* bacterial counts. *Proper handling* also contributes to satisfactory shelf life, as well as appearance, flavor, and nutritive value.

The *temperature* of raw milk should reach 40° F (4° C) or less within 2 hours of being milked. It should be kept well chilled, as it is highly perishable and susceptible to bacterial growth. The shelf life for properly refrigerated milk is 14 days or up to 45 days for *ultrapasteurized* milk products including cream, lactose-reduced milk, and so forth (see Pasteurization).

Several factors lead to the spread of diseases by milk or milk products. A contaminated cow, *cross-contamination* at the farm or from workers hands, or unsanitary equipment or utensils may all become problematic. Traditionally, the diseases of *diphtheria*, *salmonellosis*, *typhoid fever*, *tuberculosis*, and *undulant fever* were spread by consumption of unsafe milk. Today, the incidence of these diseases is *rarely* attributed to milk transmission, as milk is pasteurized to destroy pathogens. The control of insects and rodents, as well as separation of animal waste products from the milking area, also is necessary for safe milk production.

The *United States* Department of Agriculture (USDA) and state departments of agriculture regulate milk and milk products in interstate and intrastate commerce. Grades are based on bacterial counts. Grade “A” milk is available to the consumer for sale as fluid milk, although grades “B” and “C,” with higher bacterial counts, are also safe and wholesome. The grades of US Extra and US Standard are given to dried milk. USDA official grades are given to all inspected milk on a voluntary fee-for-service basis.

FLAVOR OF MILK

The flavor of milk is mild and slightly sweet. The characteristic mouthfeel is due to the presence of emulsified fat, colloidally dispersed proteins, the carbohydrate lactose, and milk salts. Fresh milk contains acetone, acetaldehyde, methyl ketones, and short-chain fatty acids that provide aroma.

Less desirable, “barny” or rancid flavors, or other “off-flavors,” may be due to the following:

- Slightly *“cooked” flavor* from excessive pasteurization temperatures.
- *Animal feed*, including ragweed and other weeds, or wild onion from the field.
- *Lipase activity* causes rancidity of the fat, unless destroyed by the heat of pasteurization. (Or, the short-chain butyric acid may produce an off-odor or off-flavor due to bacteria rather than lipase in the emulsified water of milk.)

- *Oxidation* of fat or phospholipids in the fat globule membrane, especially in emulsified, homogenized milk. Adequate pasteurization temperatures are necessary to destroy the enzyme which oxidizes fat.
- *Light-induced* flavor changes in the proteins and riboflavin because riboflavin acts as a photosynthesizer.
- *Stage of lactation* of the cow.

"*Flavor treatment*" to standardize the odor and flavor typically follows *pasteurization*. In this treatment process, milk is instantly heated to 195° F (91° C) with live steam (injected directly into the product), and subsequently subject to a vacuum that removes volatile off-flavors and evaporates excess water produced from the steam.

MILK PROCESSING

Pasteurization

"Pasteurized, when used to describe a dairy ingredient means that every particle of such ingredient shall have been heated in properly operated equipment to one of the temperatures (specified in the table) and held continuously at or above that temperature for the specified time (or other time/temperature relationship which has been demonstrated to be equivalent thereto in microbial destruction)" (FDA).

Fluid milk is *not routinely sterilized* (see below) but *rather, it is pasteurized*. This assures destruction of the pathogenic bacteria, yeasts, and molds, as well as 95–99% of nonpathogenic bacteria. ***Pasteurization*** minimizes the likelihood of disease and extends the storage life of milk.

Pasteurization temperatures do *not* change milk components to any great extent (see Nutritive Value). Vitamin destruction and protein denaturation are minimal and the result is that milk is made safe for consumption. Several acceptable methods of pasteurization include thermal processing according to the following.

- 145° F (63° C) for 30 or more minutes; the batch or holding method and is considered low-temperature longer time (LTLT) pasteurization.
- 161° F (72° C) for 15 seconds; the flash method and is the High-Temperature Short-Time (HTST) method of pasteurization.
- 191° F (88° C) for 1 second.
- 194° F (90° C) for 0.5 second.
- 201° F (94° C) for 0.1 second.
- 204° F (96° C) for 0.05 second.
- 212° F (100° C) for 0.01 second.

Pasteurization is required of all grade A fluid milk or milk products subject to interstate commerce for retail sale. Traditionally, prevention of tuberculosis

(TB) was the primary concern in pasteurization; thus, temperatures of 143° F (62° C) were used to destroy *Mycobacterium* tuberculosis, the bacteria causing TB in humans. Actually, *Coxiella burnetii* which causes Q fever requires an even *higher* temperature for destruction; thus the required 145° F (63° C) for pasteurization. The high pasteurization temperature, followed by rapid cooling, controls nonpathogenic growth.

A large US foodborne illness outbreak in recent years, where many thousands of people became ill, was attributed to raw milk that entered the wrong pipeline before packaging. It subsequently contaminated already pasteurized milk.

Many foods use enzyme tests. *Adequate* pasteurization is demonstrated by the absence of the enzyme *alkaline phosphatase* (previously listed in this chapter under protein). This enzyme is *naturally* present in milk, but is *destroyed* at temperatures similar to those required for adequate pasteurization. A simple test determines its presence in milk. For example, *inadequate* pasteurization of raw milk reveals the presence of a high alkaline phosphatase activity. Inversely, *adequate* pasteurization shows its absence.

Sterilization (ultrapasteurization) is pasteurization that occurs at *higher* temperatures with a different time:

- 280–302° F (138–150° C) for 2–6 seconds
- "Ultrapasteurized when used to describe a dairy ingredient means that such ingredient shall have been thermally processed at or above 280 degrees F for at least 2 seconds."

The use of *sterilization temperatures* in combination with the use of *presterilized containers*, under *sterile conditions*, creates ultra high temperatures (UHT) processing. It *does not* allow spoilage or pathogenic bacteria to enter the milk. If *packaging too* is sterilized, the package is referred to as being "*aseptically* packaged." Thus, milk treated in this manner may be safely stored up to 3 months or longer. An example of this is milk in packaging similar to "juice boxes."

The processing, filling and packaging of aseptic food continues to offer more mainstream technology availability.

Homogenization

The primary *function* of **homogenization** is to *prevent creaming*, or the rising of fat to the top of the container of milk (whole or some low-fat milk). The *result* is that milk maintains a more uniform composition with improved body and texture, a whiter appearance, richer flavor, and more digestible curd.

Homogenization *mechanically* increases the number and *reduces* the size of the fat globules. The size is reduced from 18 m to less than 2 m, or 1/10 of their original size. The process of homogenization permanently *emulsifies* the fine fat globules by a method that pumps milk under high pressure [2000–2500 lb/in^2 (psi)] through small mesh orifices of a homogenizer.

Homogenization offers a *permanent* emulsification because as the surfaces of many new fat globules are formed, each fat globule becomes coated with a part of the lipoprotein membrane and additional proteins from casein and whey. Thus, these proteins adsorb onto the freshly created oil surface, *preventing* globules from reuniting or coalescing, and the fat remains homogeneously distributed throughout milk.

Milk may be homogenized *prior* to or *subsequent* to pasteurization. The homogenization process is completed at a *fast* rate to ensure the control of bacteria and loss of quality.

Some characteristics of homogenized milk include the following:

- *No creaming* or separation of cream to the top of the container.
- *Whiter* milk due to a finer dispersions of fat. There is an increase in the absorption and reflection of light due to the smaller fat particles.
- *More viscous* and creamy milk due to a greater number of fat particles.
- *More bland* due to smaller fat particles.
- *Decreased fat stability* as fat globule membranes are broken.
- *Less stable to light* and may exhibit light-induced favor deterioration by sunlight or fluorescent light. Thus, paperboard cartons and clouded plastic bottles are used for milk.

Fortification

The addition of fat-soluble vitamins A and D to *whole milk* is optional. Low-fat milk, nonfat milk, and low-fat chocolate milk *must* be ***fortified*** (usually before pasteurization) to carry 2000 international units (IU) or 140 retinol equivalents (RE) *vitamin A* per quart. It is *required* for milk subjected to *interstate* commerce. *Vitamin D* to reach levels of 400 IU's per quart is *optional* but routinely practiced. Evaporated milks must be fortified.

CULINARY ALERT! Vitamin A and D are fat-soluble vitamins, thus are not naturally in milk without fat; therefore low/nonfat milk is fortified to contain these vitamins.

To increase the viscosity and appearance, as well as the nutritive value of low-fat milk, *nonfat milk solids (MSNF)* may be *added* to milk. This addition allows milk to reach a 10% MSNF (versus 8.25% usually present), and it will state "protein fortified" or "fortified with protein" on the label.

Bleaching

Bleaching carotenoid or chlorophyll pigments in milk may be desirable. The FDA allows benzoyl peroxide or a blend of it with potassium alum, calcium sulfate, or magnesium carbonate to be used as a bleaching agent in milk. The weight of benzoyl peroxide must not exceed 0.002% of the weight of the milk, and the potassium alum, calcium sulfate, and magnesium carbonate, individually or combined, must not be more than six times the weight of the benzoyl peroxide. Vitamin A or its precursors *may be destroyed* in the bleaching process; therefore, sufficient vitamin A is added into the milk, or in the case of cheese-making to the curd.

TYPES OF MILK

Fluid Milk

Milk may come from goats (Mediterranian countries), sheep (southern Europe), reindeer (northern Europe), and other animal sources throughout the world. It is *Holstein* cows that typically produce the greatest quantity of milk, and therefore are the *primary milk cow* in the United States. The Guernsey and Jersey breeds produce milk with the highest percentage of fat—approximately 5% fat.

Milk appears *white* due to the reflection of light from colloidally dispersed casein protein and calcium phosphate particles in the milk dispersion; however, an *off-white* color may be due to carotenoid pigment in the animal feed. A *bluish* color may be observed in milk skimmed of fat, and thus devoid of carotenoid pigments.

Both the fat content and percent of MSNF of fluid milk are subject to FDA regulations and new technological developments. The butterfat and caloric content of milk are as follows:

Type of Milk	Fat Percent	Calories
Whole	3.25%	150 cal/8 oz
Reduced fat	2%	120 cal/8 oz
Low-fat or light	0.5, 1.0%	100 cal/8 oz (1%)
Nonfat, fat-free/“skim”	< 0.5%	90 cal/8 oz

Flavored milk contains fat, protein, vitamin, and mineral contents similar to the type of milk to which the flavoring was added: whole, reduced fat, and so forth. It will vary in caloric and carbohydrate values according to added ingredients.

CULINARY ALERT!

Substitutes for 1 cup whole milk:

- 1/2 cup evaporated milk + $\frac{1}{2}$ cup water, reconstituted
- 1/3 cup NFMS in measuring cup + water to reach 1 cup mark of cup, reconstituted
- 1 cup buttermilk + $\frac{1}{2}$ tsp baking soda

Evaporated and Concentrated Milks

Evaporation and *condensation*, coupled with packaging in cans, extends the shelf life of milk. Cans of evaporated milk may be adequately stored for extended time periods, although due to the Maillard reaction, undesirable tan or brownish color or flavor changes may occur after 1 year. Rehydration may be made difficult.

CULINARY ALERT! Discoloration is not indicative of possible foodborne illness. Once the can has been opened, it should be refrigerated and may be held in a another container for up to 1 week.

Evaporated milk is concentrated through the process of evaporation [at 122–131° F (50–55° C)] in a vacuum chamber. Either *whole* or *nonfat* milk with 60% of the water removed is then homogenized, fortified with vitamins A and D, canned, and sterilized in the can [240–245° F (115–118° C)] in a pressure canner.

Whole evaporated milk must contain not less than 25% total milk solids and not less than 7.5% milkfat. Evaporated nonfat milk must contain not less than 20% milk solids and no more than 0.5% milkfat. It must be fortified with 125 and 25 IU of vitamins A and D, respectively.

Milk is increasingly *less* stable with the progression of concentration and heat and it may coagulate, so the stabilization of milk proteins is better assured by preheating (forewarming) milk prior to sterilization at temperatures of 203° F (95° C) for 10–20 minutes. This *forewarming* is designed to denature colloidally dispersed serum proteins and to shift salt balance of calcium chloride and phosphates that are in solution. Disodium phosphate or *carrageenan* may be added to stabilize casein against precipitation (Chapter 5).

As mentioned, an undesirable browning may occur in canned milk. The high temperature used in processing evaporated milk or long storage of the product may produce a *light tan* color due to the early stages of the ***Maillard reaction*** between the milk protein and the milk sugar, lactose. This is *not* a microbial threat (see Safety/Quality of Milk).

CULINARY ALERT! Evaporated milk is reconstituted (rehydrated) at a 1:1 ratio of evaporated milk and water, adding slightly less water than was removed in the 60% evaporation.

Sweetened condensed milk is concentrated whole or nonfat milk with approximately 60% of the water removed and sugar levels of 40–45% in the finished product. There is a calorie difference in this milk processing, as whole sweetened condensed milk contains no less than 8% milkfat and 28% total milk solids and nonfat contains no more than 0.5% milkfat and 24% total milk solids.

Sweetened condensed milk is *pasteurized*, but *not sterilized*, because the *high* sugar content (usually at least 60% in the water phase) plays a role in preventing bacterial growth. This is due to the *osmotic* effect of the sugar that competes with the bacteria for water, and thus, controls bacterial growth.

Dried Milk

Dried milk powder may be processed from either pasteurized *whole* or more commonly from *nonfat* milk. One method of drying involves *spray* drying. Milk is first condensed by removing twothirds of the water and is typically sprayed into a heated vacuum chamber (spray drying) to dry to less than 5% moisture levels. The drying process has *no* appreciable effect on the nutritive value of milk (National Dairy Council). Most nonfat dried milk is fortified with vitamins A and D.

"*Instant*" nonfat dry milk, or "*agglomerated*" milk has some moisture added back to the spray-dried milk powder. It is easily pourable and dispersible in cold water. The taste is best when it is prepared ahead and served well-chilled.

CULINARY ALERT! Three and a half ounces (1–1/3 cups) of dried milk powder is needed to yield 1 quart of fluid milk. Nonfat dried milk (NFDM) may be added to foods to increase the protein or calcium content.

In addition to whole or nonfat milk, *buttermilk* and *whey* may also be dried. Whey is of high biological value, containing lactalbumins and lactoglobulins, with *onehalf* of the protein and slightly *more* lactose than NFDM. Dried milk is an economical form of milk for shipping, has an extended shelf life, and is useful for addition to numerous other foods.

Cultured Milk/Fermentation

Cultured products are ***fermented*** by the addition of bacterial cultures, such as *lactobacilli and streptococci*, to fluid dairy products. These harmless bacteria (or bacterial enzymes) induce a chemical change in the organic substrates of milk solids. Lactose is fermented to lactic acid creating a low pH in the process, which (1) controls both spoilage and pathogenic bacterial growth, and (2) causes the casein to coagulate.

In earlier days, warm milk from various animals (cows, sheep, goats, camels) was preserved for several days or weeks, with no need for refrigeration. This was achieved by the addition of a small milk culture from a preceding batch.

Acidified products are produced by *souring* milk with an acid such as lactic, citric, phosphoric, or tartaric acid with or without microorganisms. The addition of lactic acid-producing bacteria is optional, and because cultured and acidified products contain different amounts of lactic acid, they differ in flavor. The following are examples of some commonly *cultured* milk products:

- ***Buttermilk***
  Traditionally buttermilk was the liquid that *remained* when cream was churned to form butter. It was a by-product. *Today*, this is *not* the case commercially, because low-fat or skim milk, *not* cream begins the process. Although its name (*butter* milk) may mistakenly signify a high-fat content, the opposite is true! It is more correctly named "cultured low-fat milk" or "cultured nonfat

milk." Buttermilk differs from nonfat milk in that it contains phospholipids and protein from the fat globule membrane, whereas nonfat milk does not.

- ***Cultured buttermilk***
  This is the pasteurized low-fat, nonfat, or whole milk to which a starter culture of *Lactobacillus and Streptococcus* (*S. lactis*) is added after the mix has been heated and then cooled. These bacteria ferment lactose, producing lactic acid, which clots the milk. Butter flakes or liquid butter, or low levels (0.01–0.15%) of salt, may be added. *Leuconostoc citrovorum* and *L. dextranicum* bacteria, 0.2% citric acid, or sodium citrate may be added for flavor.

- **Sour cream**
  Traditionally sour cream was made from heavy (whipping) cream that was soured. *Today*, it is made from pasteurized, homogenized, fresh, *light cream* (approximately 18% fat, depending on individual state laws) that is coagulated by a method similar to buttermilk (recall that while *buttermilk* starts *with low-fat or skim milk, sour cream* production begins with *18% fat, or perhaps cream*). While inoculation and fermentation steps are *similar* to buttermilk production, fermentation is shortened.

  S. lactis and *Leuconostoc* bacteria may be added for flavor, and stabilizers such as gelatin or gums may be present. *Nonfat milk solids* may be *added* to thicken the cream. A bitter taste in sour cream that is stored more than 3–4 weeks may form due to proteolytic bacterial enzyme activity.

- **Yogurt**
  Yogurt is the food produced by culturing one or more of the pasteurized fluid dairy ingredients such as cream, milk, partially skimmed milk, or skim milk (used alone or in combination depending on the desired fat content) with a bacteria culture. In industrialized regions of the world, yogurt is made with cow's milk.

  The milk is both pasteurized and homogenized *before* the addition of a starter that contains the lactic-acid producing bacteria, *L. bulgaricus* and *S. thermophilus.* The process used to make yogurt is similar to buttermilk and sour cream, but the incubation temperature and types of bacteria are different.

  Yogurt may be made using whole, low-fat or skim milk. The formulation may include nonfat dry milk (NFDM) or condensed skim milk to boost its solids. It contains not less than 8.5% MSNF and not less than 3.25% milkfat. Or it may be prepared to be a reduced or low-fat yogurt and have levels of 0.5–2.0% milkfat, or less. Other optional ingredients include buttermilk, whey, lactose, lactalbumins, lactoglobulins, or whey modified by partial or complete removal of lactose and/or minerals to increase the nonfat solid contents of the food. New research and development continues to explore additional optional ingredients.

  Microorganisms in yogurt exist in a "*friendly*" form, known as *probiotic flora.* Such probiotic yogurt, with *Lactobacillus* and *Bifidobacterium*, is able to survive destruction during gastrointestinal (GI) passage and offer health benefits such as immune stimulation and positive balance to the GI microflora

(1). The Food and Agriculture Organization of the United Nations (FAO) defines probiotics as “live microorganisms administered in adequate amounts which confer a beneficial health effect on the host”. Most probiotics are bacteria one is a yeast and (*Saccharomyces boulardii*) (2). The National Yogurt Association’s “live and active cultures” seal indicates that the yogurt contains at least 100 million *L. acidophilus* bacteria per gram at the time it is manufactured, although this number diminishes with time (3), and the microbial enzyme lactase (3).

Frozen yogurt may contain stabilizers for freezer stability, sugar, and added milk solids. The different types of yogurt, including sundae-style or blended, swiss yogurt, are cultured and stored in different manners. Nutritive or nonnutritive sweeteners may be added, as well as flavoring agents, color additives, and stabilizers such as gelatin, gums, and pectin (Chapter 17).

- **Acidophilus milk**
  Acidophilus milk is a cultured product made from pasteurized low-fat, nonfat, or whole milk. *Lactobacillus acidophilus* is added and incubated at 99° F (37° C). Although *not* proven yet, a possible *benefit* of consumption is that ingestion can produce a number of B vitamins, thereby replacing what may have been destroyed during antibiotic treatment. A variation of this is sweet acidophilus milk. This sweet version has culture added; however, it is not incubated. It is thought to be therapeutic without the characteristic high acidity and flavor.

  Acidophilus produces the enzyme lactase and helps correct the symptoms of lactose intolerance. It is thought that lactase in combination with *L. acidophilis* is enabled to pass successfully through the stomach acids and reach the small intestine where it functions in lactose digestion, preventing the discomfort experienced by those individuals who are lactose intolerant and unable to digest lactose (National Dairy Council).

- **Kefir**
  Kefir is another less well-known, fermented, probiotic milk product. It contains the bacteria *Lactobacillus caucasius* and the yeasts *Saccharomyces kefir* and *Torula kefir*. As well, it is slightly bubbly due to the fermentation process and it contains approximately 1% alcohol.

  Other specialty types of milk include low-sodium, lactose-reduced milk, calcium-fortified, as well as flavored milks and shakes. Nonmilks such as rice and soy “milk” also are consumed. The latter are especially useful to persons who are lactose intolerant.

OTHER MILK PRODUCTS

Butter

Butter is a concentrated form of fluid milk produced through churning of pasteurized cream. ***Churning*** involves agitation that breaks fat globule membranes so the emulsion breaks, fat coalesces, and water (buttermilk) escapes. Emulsions may be of two types. The original 20/80 *oil-in-water* type of emulsion of milk becomes a 20/80 *water-in-oil* emulsion. Milk is churned to form butter and the watery buttermilk. Butter may have a yellow color due to the fat-soluble animal pigment, carotene, or an additive.

Today, there are various blends of butter and margarine in the market. The fat composition and taste differ from the original. Margarine, or oleomargarine, is the food in plastic form or liquid emulsion containing not less than 80% fat. It may be produced from water and/or milk and/or milk product and it may be unsalted or lactose-free. It contains vitamin A and may contain vitamin D.

Sweet cream butter is made by the addition of *S. diacetyllactis*, which ferments the citrate in milk to acetaldehyde, acetic acid, and diacetyl, the last being the major flavor compound of butter. Commercially, it may contain salt, yet it is known as "sweet cream" butter, because today the butter is prepared from sweet and not the traditional soured cream. The USDA grade AA is of superior quality, USDA grade A is very good, and grade B is standard. *Spreads* contain a higher percentage of water and may not be suitable for some baking and cooking applications.

Cream

"Cream means cream, reconstituted cream, dry cream, and plastic cream. Water, in a sufficient quantity to reconstitute concentrated and dry forms, may be added" (FDA).

Cream is the high-fat component separated from whole milk as a result of the creaming process. It has a higher proportion of fat droplets to milk than regular fluid milk; and according to federal standards of identity, cream must contain *18% milkfat* or more. Due to this high fat content of cream compared to milk, some yellow, fat-soluble pigments may be apparent. Some fats are naturally small and do not coalesce.

Various liquid creams available for use in foods include the following:

- Light (coffee) cream: 18–30% butterfat.
- Light whipping cream: 30–36% butterfat.
- Heavy cream: 36% butterfat, minimum.
- "Half-and-half" cream diluted with nonfat milk: 10.5% butterfat.
- Whipping cream packaged under pressure in aerosol cans; may be nonfat or contain various levels of fat, sugar, flavoring, emulsifiers, and a stabilizer.

Cheese

The FDA's definition of cheese is "a product made from curd obtained from the whole, partly skimmed, or skimmed milk of cows, or from milk of other animals, with or without added cream, by coagulating with rennet, lactic acid, or other suitable enzyme or acid, and with or without further treatment of the separated curd by heat or pressure, or by means of ripening ferments, special molds, or seasoning" (FDA).

Cheese (Fig. 11.1) is a concentrated form of milk that contains casein, various percentages of fat, primarily saturated fat, mineral salts, and a small portion of milk serum (whey proteins, lactose, and water-soluble vitamins). It is the curd that forms as a result of casein coagulation by the enzyme rennin (also known as chymosin) or lactic acid. If mold forms on the cheese, it should be cut off deeper than what is seen. The mold may produce a toxin (mold is acceptable in certain cheeses such as blue cheese).

"Chymosin, known also as rennin, is a proteolytic enzyme synthesized by chief cells in the stomach. Its role in digestion is to curdle or coagulate milk in the stomach, a process of considerable importance in the very young animal. If milk were not coagulated, it would rapidly flow through the stomach and miss the opportunity for initial digestion of its proteins.

"Chymosin efficiently converts liquid milk to a semisolid like cottage cheese, allowing it to be retained for longer periods in the stomach. Chymosin secretion is maximal during the first few days after birth, and declines thereafter, replaced in effect by secretion of pepsin as the major gastric protease.

"Chymosin proteolytically cuts and inactivates kappa casein, converting it into para-kappa-casein and a smaller protein called macropeptide. Para-kappa-casein does not have the ability to stabilize the micellar structure and the calcium-insoluble caseins precipitate, forming a curd. . . . chymosin is also a very important industrial enzyme because it is widely used in cheesemaking. In days gone by, chymosin was extracted from dried calf stomachs for this purpose, but the cheesemaking industry has expanded beyond the supply of available calf stomachs (remember that these have to be from young calves). It turns out that many proteases are able to coagulate milk by converting casein to paracasein and

FIGURE 11.1 Cheeses (Courtesy of SYSCO® Incorporated).

alternatives to chymosin are readily available. “Rennet” is the name given to any enzymatic preparation that clots milk “(4)”.

Animal (calf, bovine pepsin), plant (papain), and microbial protease *enzymes* clot milk to form curds. Genetic engineering of bacteria has produced new options. Cheese making typically uses rennin and pepsin. Rennin produces clots that are rich in calcium (although slightly tougher curds form with rennin than with lactic acid)

- Rennin is from the stomach of milk-fed *calves.* Although rennin is active at neutral pH, the enzyme clots milk much faster in acidic conditions, such as when lactic acid is used. *Biotechnology* has enabled the *specific gene* that produces rennin to be reproduced in *bacteria without* extracts from the calves' stomach. Rennet (the commercial name for rennin) is then produced through fermentation. In fact, half of rennet in cheese production is produced through fermentation (International Food Information Council, IFIC).
- *Pepsin* is from the stomach of *pigs* (swine)
- *Proteases* from fungi
- *Plant enzymes* such as *papain* (from papaya) and *ficin* (from figs) may be used by Industry to clot milk casein and form some cheeses.

In general, cheese is classified according to (1) the moisture content, producing either very hard, hard, semisoft, or soft cheeses, and (2) the kind and extent of ripening. A brief explanation appears below.

Moisture Content

- *Hard cheese* contains 30–40% water. It has very tiny fat globules and is a near-perfect emulsion.
- *Soft cheese* contains 40–75% water and has large fat globules. It is only slightly emulsified.

Ripening

Ripening may require 2–12 months. In that time, the

- *carbohydrate* lactose is fermented by lactase to lactic acid,
- *fat* is hydrolyzed by lipase, and
- *protein* undergoes mild proteolysis to amino acids by rennin.

Ripening refers to the *chemical and physical changes* that occur in the cheese in the time between curd precipitation and satisfactory completion of texture, flavor, aroma, and color development. Ripening modifies the characteristics mentioned, as well as continuing to ferment residual lactose. It may be due to bacteria, bacterial enzymes (chiefly rennin), or the fungus mold and yeast. Some example follow:

- Cheeses, such as cottage cheese or cream cheese, are *not* ripened.
- Cheeses may be *ripened with bacteria*. For example, the holes or eye formation in Swiss cheese is evidence of gas-producing bacteria that exist throughout the interior of the cheese.
- Cheeses, such as brick and Limburger, are *ripened* by inoculation of the milk with *bacteria* and *yeast*. These microorganisms ripen from the surface to the interior of the cheese.
- Camembert and Brie, for example, are ripened by mold that is sprayed onto the surface of the cheese, or mold may be introduced internally as in the *ripening* of blue cheese that is inoculated with *Penicillium roqueforti*.

According to USDA 2000 statistics, the commercial volume jumped 6%, with the average personal consumption rising to 30.3 pounds. In descending order, American, cheddar, and mozzarella cheese are by far the leaders in sales, followed by a distant Monterey Jack, Swiss, and Colby cheese.

A starter culture added to milk begins curd development. Once a curd has formed, it is cut, cooked to shrink the curd, and drained of any remaining whey (syneresis). Next it is salted to provide flavor, draw whey from the curd, and retard microbial growth. The curd then is pressed and fermented with various microorganisms at 40–55° F (4–13° C).

An example of a cheese made with lactic acid is cottage cheese. The origins were not in industry, but individual "cottages." Thus, the name. Cottage cheese is a no/low-fat, soft, acid cheese formed by coagulation of casein with lactic acid. It is made from pasteurized skim milk, to which is added *either* lactic acid or a bacterial culture that produces lactic acid to reduce the pH to 4.6.

CULINARY ALERT! Blue cheese is made from cow's milk; Roquefort cheese is made from sheep's milk. If other cheeses show mold, they can be consumed if mold is cut away deeper that what can be seen. It is recommended to cut off ¼ to 1 inch of product.

Cheese is cut and packaged under hundreds of names worldwide. Despite the abundance of names given to various cheeses throughout the world, there are only approximately 18 types that differ in flavor and texture (5). These types are listed as follows:

- Brick (United States)—semisoft, ripened primarily by bacteria
- Camembert (France)—soft, mold externally applied (*Oidum lactis* and then *P. camemberti*); thin edible crust
- Cheddar (England)—hard, bacteria-ripened (*S. lactis and S. cremoris*); most commonly cheese used for cooking in the United States, colored by annatto (a seed pod extract)
- Cottage cheese—soft, unripened; creamed, low-fat, nonfat, or dry curd
- Cream cheese (United States)—soft, unripened; may be flavored

- Edam (the Netherlands)—hard, ripened; ball-shaped with a red-paraffin coating
- Gouda (the Netherlands)—semisoft to hard, ripened; similar to Edam
- Hand—soft
- Limburger (Belgium)—soft, surface bacteria ripened (*Bacterium linens*)
- Neufchatel (France)—soft, unripened in the United States; ripened in France
- Parmesan (Italy)—hard, bacteria ripened
- Provolone (Italy)—hard, ripened
- Romano (Italy)—very hard, ripened
- Roquefort (France)—semisoft, internally mold ripened (*P. roqueforti*)
- Sap Sago (Switzerland)—very hard, ripened by bacteria
- Swiss, Emmentaler (Switzerland)—hard, ripened by gas-forming bacteria (*S. lactis* or *S. cremoris,* and *S. thermophilus, S. bulgaricus,* and *P. shermani*).
- Trapist—semisoft, ripened by bacteria and surface microorganisms
- Whey cheeses, such as ricotta (Italy), which may be a combination of whole and low-fat milk, or whey; coagulated by heating, not rennin (5); some definition in 4th^{d} ed.

In the United States, the FDA has requirements for specific standardized cheese that must be followed by manufacturers, packers, and distributors. In addition to the list above, some other standardized cheese types include Asiago, Caciocavello Siciliano, Colby, Gammelost, Gorgonzola, Gruyere, Monterey Jack, mozzarella, Muenster, Nuworld, and Samsoe.

More details of the types of cheese available to the consumer are listed and explained below:

- *Natural cheese* is the curd of precipitated casein. It may be overcoagulated and allow water to be squeezed out or the fat emulsion to break when exposed to *high* heat, in which case it shows a separated appearance and stringy texture. Therefore, *low* heat should be used when cooking with natural cheese.
- *Pasteurized process(ed) cheese* is the most common cheese produced in the United States. By FDA ruling, it is "prepared by comminuting and mixing, with the aid of heat, one or more cheeses of the same, or two or more varieties, except cream cheese, neufchatel cheese, cottage cheese, low-fat cottage cheese, cottage cheese dry curd, cook cheese, hard grating cheese, semisoft, part-skim cheese, part-skim spiced cheese, and skim milk cheese for manufacturing with an emulsifying agent . . . into a homogeneous plastic mass" (CFR).

The mixture is pasteurized (which halts ripening and flavor development) for 3 minutes at 150° F (66° C) and salt is added. An emulsifier such as disodium phosphate or sodium citrate is incorporated to bind the calcium and produce a more soluble, homogeneous, and smooth cheese that can withstand higher heat than natural cheese without coagulating. The melted cheese is placed in jars or molds such as foil-lined cardboard boxes or single-slice plastic wrap.

This cheese also may contain an optional mold-inhibiting ingredient consisting of not more than 0.2% by weight of sorbic acid, potassium sorbate, sodium sorbate, or any combination of two or more of these, or consisting of not more than 0.3% by weight of sodium propionate, calcium propionate, or a combination of sodium and calcium propionate. It may contain pimentos, fruits, vegetables, or meats.

The moisture content of a process cheese made from a single variety of cheese is not more than 1% greater than the maximum moisture content prescribed by the definition and standard of identity for the variety of cheese used, if there is one. In no case is the moisture to be more than 43% (except 40% for process washed curd and process Colby cheese, and 44% process Swiss and Gruyere).

The moisture content of a process cheese made from two or more varieties of cheese is not more than 1% greater than the arithmetical average of the maximum moisture contents prescribed by the definitions and standards of identity, if there is one, for the cheeses used. In no case is the moisture content more than 43% (40% cheddar, Colby, 44% Swiss and Gruyere).

The fat content of process cheese made from a single variety of cheese is not less than the minimum prescribed by the definition and standard of identity for the variety of cheese used, and in no case is less than 47% (except process Swiss 43% and process Gruyere 45%). The fat content of process cheese made from two or more varieties of cheese is not less than the arithmetical average of the two cheeses, as described above, and in no case is less than 47% (except the mixture of Swiss and Gruyere 45%). Low-fat processed cheese demonstrates an improvement in texture and meltability when *Oatrim*, a glucan-amylodextrin, is added at low levels (Chapter 12) (6).

- *Pasteurized process(ed) cheese food* is comminuted and mixed and contains not less than 51% cheese by weight. The moisture is not more than 44%, and the fat content is not less than 23%. Thus, it contains less cheese and more moisture than process cheese. It may contain cream, milk, nonfat milk, NDM, whey, and other color or flavoring agents. It has a soft texture and melts easily. An emulsifying agent may be added in such quantity that the weight of the solids of such an emulsifying agent is not more than 3% of the weight of the pasteurized process cheese food (FDA).
- *Pasteurized process cheese spread* is comminuted and mixed. It has a moisture content of 44–60%, and a milk fat level of not less than 20%. Therefore, it has more moisture and less fat than processed cheese food and can be spread. Gelatin and gums such as carob bean, cellulose gum (carboxymethylcellulose), guar, tragacanth, and xanthan, as well as carrageenan, may be added if such substances are not more than 0.8% of the weight of the finished product (FDA). Sodium may be added to retain moisture and sugar or corn syrup may be added for sweetness.

- *Cold-pack cheese* preparation involves grinding and mixing natural cheese without heat. The moisture content of a cold-pack cheese made from a single variety of cheese is not more than the maximum prescribed for the variety of cheese used (if there is a standard of identity), and the fat content is not less than the minimum prescribed for that cheese, but is not less than 47% (except 43% cold-pack Swiss, and 45% Gruyere).

While cold-pack cheeses that may contain various flavor combinations, manufacturers have the technology to create custom-colored and custom-flavored specialty cheeses as needed (7). When made from two or more varieties of cheese, the moisture content should be the arithmetical average of the maximum of the two cheeses, as prescribed by the definition or standard of identity, but in no case more than 42%. The fat content is not less than the arithmetical average of the minimum percent of fat prescribed for the cheeses, if there is a standard of identity or definition, but in no case less than 47% (cold-pack Swiss and Gruyere 45%).

The lactose content of ripened cheese *decreases* during ripening and is virtually *absent* in several weeks. It is the whey that contains lactose, which some individuals cannot consume (lactose intolerance). The majority of vitamins and minerals remain after ripening, some protein is hydrolyzed by rennin or proteases, and some fat is digested. Grades of US grade AA and A are assigned to some commonly consumed cheeses such as cheddar and Swiss cheese.

CULINARY ALERT! Tips for lengthening shelf life of cheese involve cold storage and lowering the pH. This is achieved by refrigeration and wrapping in a vinegar-soaked cheesecloth.

According to a research study by Oregon State University, "Imitation cheese is made from vegetable oil: it is less expensive, but also has less flavor and doesn't melt well. For the record, *Velveeta*® is pasteurized process cheese spread and *Velveeta Light*® is pasteurized process cheese product. *Cheez Whiz*® is labeled as pasteurized process cheese sauce, although that type isn't noted in the *Code of Federal Regulations*" (8).

Ice Cream

Ice cream is sometimes referred to as an "indulgent" food, meaning that while fat is reduced elsewhere in the diet, ice cream consumption may not decrease! While ice mixes were enjoyed for centuries prior to this, the first commercial, wholesale ice cream was manufactured in 1851, in Baltimore, Maryland.

It is a food produced by freezing, while stirring a pasteurized mix containing *dairy* product. The mix consists of one or more dairy ingredients such as cream, milk, skim milk, sweet cream buttermilk or sweetened condensed milk, and optional caseinates. *In addition* to the dairy ingredient, sherbet, low-fat ice cream, and ice creams contain other ingredients. Typically, sugar (sucrose, dextrose, which flavors and depresses the freezing point), cookies, eggs, fruit, nuts, and other ingredients such as coloring or flavoring agents, emulsifiers [such as egg yolks, polysorbate 80 (a sorbitol ester consisting of a glucose molecule bound to the fatty acid; oleic acid), or mono and diglycerides], stabilizers (gelatin, vegetable gum), and water are added.

The ice cream mix is subject to pasteurization, homogenization, holding (for aging), and quick freezing. Slow freezing creates larger ice crystals. Air is naturally incorporated into an ice cream mixture by agitation, but excessive air may not be whipped into a mix as specified by federal and state standards. The increase in volume due to air is ***overrun***, and is calculated as

$$\boxed{\%\ \text{Overrun} = (\text{Volume of ice cream} - \text{Volume of mix}) \times 100 = \text{Volume of mix}}$$

For example, if a 1-gallon container of ice cream contains an equal measure of ice cream mix and air, it has 100% overrun. Overrun in ice creams may range from 60% to greater than 100%.

- **Ice cream** contains not less than 10% milkfat nor less than 10% MSNF, except when it contains milkfat at 1% increments above the 10% minimum.
- **Low-fat ice cream** (formerly ice milk) contains less fat and more MSNF and deluxe ice cream contains more milkfat and less MSNF. Other frozen desserts may include milk and varying percentages of milkfat or perhaps a fat substitute.
- **Blended milk products** are fruit juices and milk that may contain added lactic acid or caffeine, plus other ingredients, and may be prepared using herb teas and additional sugars.
- **Sherbet** contains 1–2% milk fat and 2–5% total milk solids. A greater amount of sugar and less air (hence 30–40% overrun) than ice cream are standard.

Percent milkfat	Minimum percent MSNF
10	10
11	9
12	8
13	7
14	6

WHEY

Whey previously has been discussed as the aqueous (serum) protein in milk, but it warrants further discussion due to its *increasing* use in consumer products. Research is ongoing to target separating milk serum proteins from liquid milk prior to cheesemaking (9). Some cheese such as ricotta cheese may be made *partially* of whey.

As has been mentioned, whey comprises approximately *20%* of the protein in milk. It contains the albumins and globulins, the majority of *lactose*, and the water-soluble nutrients, such as riboflavin. Whey is the *by-product* of cheesemaking, the liquid that remains after curds are formed and drained (recall the nursery rhyme Little Miss Muffet, eating her curds and whey!). A tremendous quantity of cheese is manufactured and currently more satisfactory ways of using whey are being explored.

Whey is a nutritious product. It also may be used in beverages, frozen dairy desserts, and baked goods. In a dried form, it may have useful applications as an emulsifier and in providing extra protein to foods. Whey also has foaming and gelling applications. Yet, because it contains lactose, which the majority of the world cannot digest (see Lactose Intolerance), it *cannot* be used in worldwide feeding.

Whey begins to precipitate at temperatures below the coagulation temperature of casein, yet it is not precipitated at a pH of 4.6 or by rennin, as is casein. Evidence of whey precipitation is seen when the lactalbumin coagulum (as well as calcium phosphate) sticks to the bottom of the pan and scorches.

In addition to some uses previously listed, whey is concentrated by ultrafiltration to yield *whey protein concentrates* (WPCs). WPCs frequently are added to yogurt and dried for use in such items as coffee whitener, whipped toppings, meringue, fruit beverages, chocolate drinks, and processed meats.

Further purification steps may be added to yield *whey protein isolates* (WPIs). For example, WPIs are used in infant formulas and whey refinery may yield proteins used to fortify clear bottled drinks, including sodas. Fractionation in the whey refining process could lead to products without phenylalanine, and thus to products useful to people with phenylketonuria (PKU) (10).

COOKING APPLICATIONS

Subsequent to the mild denaturation or change in molecular structure of proteins, cross-links are formed. ***Coagulation*** and precipitation of clumps or aggregates may occur with heat or when acid, enzymes, or salts are in a formulation. Some of these effects are as follows:

- **Heat**, especially direct or high heat, may *denature*, *coagulate, or curdle* milk. Slow, *low*, or moderate heat such as indirect heating over a water bath should be used for milk-based products. Increasing temperatures and length of heating may break the fat emulsion if the protein film around the fat globules breaks. Thus the fat will coalesce. *High* heat also forms greater amounts of coagulum at the bottom of the pan than low heat.

The *same* calcium phosphate compound that forms at the bottom of the pan by scorching also forms a skin (scum or film) at the surface of the food as water evaporates. This surface skin may “hold in” heat and lead to a boilover of the milk product subjected to heat. Prevention includes use of a pan lid or surface application of an agent such as fat.

CULINARY ALERT! Cooking and storing with a cover is recommended in order to prevent this skin formation.

- **Acid** may come from a variety of sources. It can be *added* to food or be a *part* of a food or it may be produced by bacteria. It coagulates milk mixtures by forming unstable *casein* proteins. Casein precipitates at a pH of approximately 4.6 (recall that *whey* proteins are not precipitated by acid). Use of a white sauce may control precipitation.
- **Enzyme coagulation**: As will be discussed in the chapter section on Cheese, *several* sources of enzymes are responsible for coagulation and curd formation: animal, plant, or microbial enzymes. However, the *primary* enzyme used to coagulate milk in cheese or ice cream is rennin (commercially known as rennet).

Rennin requires a slightly acidic environment and functions best at temperatures of 104–108° F (40–42° C) rather than high temperatures. Calcium is retained if the coagulation of milk is achieved by rennin rather than acid (eg, some custardlike desserts and cottage cheese), because calcium is not released to whey but is held by casein.

- **Polyphenolic compound coagulation**: *Phenolic* compounds (formerly called tannins) are in some plant materials including fruits, vegetables (eg, potatoes, tomatoes), tea, and coffee and they coagulate milk. Although baking soda (alkali) may be added to milk combinations to shift the pH and control curdling, it is not recommended, as it destroys vitamin C in the product. Low heat and a gelatinized starch buffer (white sauce) may be used for controlling this undesirable coagulation.
- **Salt coagulation**: *Calcium and phosphorus salts* present in milk are less soluble with heat and may coagulate milk protein. Salty foods such as ham, as well as some vegetables and salt flavorings that are added to milk, frequently may cause the milk to curdle. As with acid-caused coagulation, a gelatinized starch buffer is used to prevent undesirable precipitation.

MILK SUBSTITUTES AND IMITATION MILK PRODUCTS

In 1973, the FDA differentiated between *imitation and substitute* products by establishing regulations regarding the use of the two names. An ***imitation milk*** product may look and taste like the traditional product but is nutritionally inferior. Specifying the term "imitation" on labels is no longer a legal requirement. A milk ***substitute*** product is one that resembles the traditional product and is nutritionally equal. A substitute is pasteurized, homogenized, and packaged like milk. It is more economical than real dairy products because it does not contain the costly butterfat.

CULINARY ALERT! Milk and milk products with the "Real" symbol on the package indicate that the product is made from real dairy products, not substitutes or imitations.

Filled Milk

Filled milk is a milk *substitute without milkfat*. It consists of a *vegetable* fat or oil and nonfat milk solids, so it is not a substitute for persons with milk allergies.

They cannot consume it. The vegetable fat has *traditionally* been coconut oil, but it may be partially hydrogenated corn, cottonseed, palm, or soy oil. Oil, water, an emulsifier such as monoglycerides or diglycerides, color such as carotene, and flavoring may be added. Filled milk contains no cholesterol.

Imitation Milk

Imitation milk usually contains *no* milk products at all—*no* milk fat or milk solids. It is composed of water, vegetable oil, corn syrup, sugar, sodium caseinate, or soy, and stabilizers and emulsifiers. Vitamins and minerals may be added to the product to improve the nutritional value.

CULINARY ALERT! Flavored "milk," "butter," "cream cheese," whipped "cream," and other imitation products are available in the marketplace. Nondairy "creamers" or whiteners are prevalent in fluid and dehydrated form.

SAFETY/QUALITY OF MILK

Milk is a highly perishable substance, high in water, with significant amount of protein and a near-neutral pH (6.6)—the qualities that *support bacteria growth*. Details of sanitation are previously mentioned, but it is important to know about the care and safety of milk. Depending on the ingredients, even nondairy imitation "milks," *may* require refrigeration or freezing comparable to the dairy product that they resemble.

Packaging contains a date on the carton that should be followed for a retail sale. Milk may remain fresh and usable for several days past this "sell-by-date" if the following directions, suggested by the Dairy Council, are observed:

- Use proper containers to protect milk from exposure to sunlight, bright daylight, and strong fluorescent light to prevent the development of off-flavor and a reduction in riboflavin, ascorbic acid, and vitamin B_6 content.
- Store milk at refrigerated temperatures [45° F (7° C)] or below as soon as possible after purchase.
- Keep milk containers closed to prevent absorption of other food flavors in the refrigerator. An absorbed flavor alters the taste but the milk is still safe.
- Use milk in the order purchased.
- Serve milk cold.
- Return milk container to the refrigerator immediately to prevent bacterial growth. Temperatures above 45° F (7° C) for fluid and cultured milk products for even a few minutes reduce shelf life. Never return unused milk to the original container.
- Keep canned milk in a cool, dry place. Once opened, it should be transferred to a clean opaque container and refrigerated.

- Store dry milk in a cool, dry place and reseal the container after opening. Humidity causes dry milk to lump and may affect flavor and color changes. If such changes occur, the milk should not be consumed. Once reconstituted, dry milk should be treated like any other fluid milk: covered and stored in the refrigerator.
- Serve UHT milk cold and store in the refrigerator after opening.

A regulatory watch is in regard to milk from cloned animals and their offspring. Currently, the International Dairy Foods Association supports a continued moratorium on usage of milk from cloned animals, and is awaiting a final ruling by the FDA. The FDA Risk Assessment underwent a peer review and utilized independent scientific experts. To date, they have found that milk from cloned animals is as safe to eat as food from animals that are conventionally bred.

Carbohydrate Browning Reactions

Color and flavor changes are observed in canned or dry milk that has been subject to either long or high-temperature storage. The browning does not indicate contamination or spoilage, rather it is the nonenzymatic ***Maillard browning*** or "carbonyl-amine browning" reaction between the free carbonyl group of a reducing sugar and the free amino group of protein.

NUTRITIVE VALUE OF MILK AND MILK PRODUCTS

The FDA ruling for dairy products, in 1996 *revoked* the "Standard of Identity" (prescribed formulation or recipe that the manufacturer needed to follow). Thus nutrient claims such as "fat-free" and others similar to those carried by other products became the *rule* for dairy labels.

An American Heart Association Recommendation: "We recommend that adults and children age 2 and older use milk that's *low* in dairy fats. This includes fortified fat-free (skim or nonfat) milk, fortified nonfat milk powder, and 1/2 percent and 1 percent low-fat milk. The label on the container should show that the milk has been fortified with *vitamins A and D*. We also recommend buttermilk made from skim milk and canned evaporated skim milk.

"Avoid substitutes that contain *coconut oil, palm oil or palm kernel oil*. These oils are very high in *saturated* fats. Saturated fats tend to raise the level of cholesterol in the blood. High blood cholesterol is one of the six major risk factors for heart disease that can be changed, treated or modified. It can also lead to developing other heart and blood vessel diseases" (AHA).

Proteins

Milk contains high-quality proteins—casein and whey. According to the American Diabetes Association (ADA) exchange list, an 8-ounce serving of fluid milk contains 8 g of protein regardless of fat content.

Fats and Cholesterol

Dairy products may be made into fat-free, low-fat, reduced fat, or cholesterol-free formulations (6, 10). For example, cholesterol-free milk is made by adding hydrolyzed oat flour (oatrim) to nonfat milk. Dairy products also may be used as a fat replacer in other foods (fat-free does not mean calorie-free). *Yogurtesse®* is the dairy-based fat replacer, introduced in 1996, that is used in products such as baked goods, sauces, and dressings. It contains no fat and is cholesterol-free. Yogurtesse® contains nonfat milk solids, whey protein, pectin, locust bean gum, carrageenan, and other components.

Labeling changes have served both to benefit processors' creativity, such as in developing "light" milk, and to better assist consumers in lowering their fat and saturated fat intake. As shown above (Types of Milk), a label may state whole milk, reduced fat, or fat-free. The calorie levels differ according to the fat content. For example, whole milk contains 150 cal per 8 ounces and skim milk contains 90 cal per 8 ounces. Cholesterol levels range from 4 mg to 33 mg per cup. According to the USDA, milk sales have indicated an increase in the sales of reduced-fat and skim milk, while there has been a decrease in full-fat, whole milk, as shown below.

Carbohydrates

The carbohydrate content of 8 ounces of milk is 12 g regardless of the level of fat. A discussion of lactose intolerance follows.

Milk sales (in billion pounds)

	1976	1996
Full-fat	26.4	18.8
Reduced fat	21.2	24.2
Fat-free	3.2	8.9

Vitamins and Minerals

The fat-soluble vitamins A, D, E, and K are present in whole and some reduced-fat milk. Fortification beyond vitamin A and D is not allowed in current standards of identity. Milk is a major source of riboflavin (B_2) in the diet of many populations. Losses of B_2 may occur due to exposure to sunlight as riboflavin is a photosynthesizer. Milk also contains the amino acid tryptophan, a precursor to niacin.

No apparent undesirable effect on protein, fat, carbohydrates, minerals, and vitamins B_6, A, D, and E are observed with pasteurization. Vitamin K is slightly diminished, and there is less than 10% loss of thiamin and vitamin B_{12}.

One 8-ounce cup (240 ml) of whole fluid cow's milk contains the following minerals: potassium, calcium, chlorine, phosphorus, sodium, sulfur, and magnesium. Milk does not contain iron. The composition of milks from different species appears in Table 11.2.

Low-sodium milk may be included in diets with sodium restrictions. Sodium may be reduced from a normal amount of 49 mg to about 2.5 mg per 100 g of milk by replacing the sodium with potassium in an ion exchange.

Trends in beverage intake show a substantial decrease in young women (12–19 years old) drinking milk. This indicates a need for intervention, perhaps including the recommendation of consumption of calcium from other sources (12). Recent trends also have shown a decrease in consumption of milk and consumption of more sugar-sweetened beverages. *Flavored milks* are an alternative to such beverages and may assist in reversing recent trends (13).

TABLE 11.2 Composition of Milks from Different Species (100-g portions)

Nutrient	Cow	Human	Buffalo	Goat	Sheep
Water (g)	87.99	87.50	83.39	87.03	80.70
Calories	61	70	97	69	108
Protein ($N \times 6.38$) (g)	3.29	1.03	3.75	3.56	5.98
Fat (g)	3.34	4.38	6.89	4.14	7.00
Carbohydrate (g)	4.66	6.89	5.18	4.45	5.36
Fiber (g)	0	0	0	0	0
Cholesterol (mg)	14	14	19	11	–
Minerals					
Calcium (mg)	119	32	169	134	193
Iron (mg)	0.05	0.03	0.12	0.05	0.10
Magnesium (mg)	13	3	31	14	18
Phosphorus (mg)	93	14	117	111	158
Potassium (mg)	152	51	178	204	136
Sodium (mg)	49	17	52	50	44
Zinc (mg)	0.38	0.17	0.22	0.30	–
Vitamins					
Ascorbic acid (mg)	0.94	5.00	2.25	1.29	4.16
Thiamin (mg)	0.038	0.014	0.052	0.048	0.065
Riboflavin (mg)	0.162	0.036	0.135	0.138	0.355
Niacin (mg)	0.084	0.177	0.091	0.277	0.417
Panthothenic acid (mg)	0.314	0.223	0.192	0.310	0.407
B_6 (mg)	0.042	0.011	0.023	0.046	–
Folate (mcg)	5	5	6	1	–
B_{12} (mcg)	0.357	0.045	0.363	0.065	0.711
Vitamin A (RE)	31	64	53	56	42
Vitamin A (IU)	126	241	178	185	147

Source: National Dairy Council.

CULINARY ALERT! There is no appreciable effect on the availability of calcium or protein to humans when normal quantities of *chocolate* are added to milk (National Dairy Council).

LACTOSE INTOLERANCE

Many individuals demonstrate a permanent loss of the enzyme used to digest the principal milk sugar lactose; they are lactose intolerant. ***Lactose intolerance*** may be due to the absence of or insufficient amount of lactase, a birth deficit, or physical impairment. Caucasians are among the *few* population groups who can digest lactose.

If lactose remains undigested by lactase in the intestine, it is fermented by microflora to short-chain fatty acids and gasses such as carbon dioxide and hydrogen and in some individuals to methane. Symptoms of lactose intolerance include flatulence, abdominal pain, and diarrhea due to the high solute concentration of undigested lactose. A correct understanding of tolerable doses may be more liberal than expected. Both the lactose-intolerant individual and the food industry may benefit. Also, acidophilus milk contains the needed enzyme lactase and is readily available at many grocery markets.

Lactose assists in the absorption of calcium, phosphorus, magnesium, zinc, and other minerals from the small intestine brush border. Nondairy "milk," such as rice or soy milk or imitation milk, contains no lactose and may be consumed by individuals with milk allergies and by those who would otherwise not drink milk.

The loss of lactase activity in the intestine to some extent, affects approximately 75% of the world's population (14). Individuals with lactose intolerance may compensate by consuming lactase-treated milk (which reduces lactose by 70%) or purchase the lactase enzyme and administer it directly to milk prior to consumption. It has been shown that small servings (120 ml = 6 g of lactose) of milk and hard cheeses (less than 2 g of lactose) may be consumed without an increase in intolerance symptoms. Hard cheeses contain less lactose than soft cheeses. Up to 12 g of lactose are tolerated, especially if the individual consumes other foods with the source of lactose (15).

Some fermented products, such as cheese, are tolerated if lactose has been sufficiently converted to lactic acid. Aged cheese is an example of such food. The lactose content of some milk and milk products is given in Table 11.3.

MARKETING MILK

The official newsroom for the national milk mustache "got milk?" campaign and the milk processor education program is found at http://www.milknewsroom.com/index.htm. This site is designed to be a resource for the media to access information about milk research, milk programs, and the national milk mustache "got milk?" campaign.

TABLE 11.3 Lactose Content of Milk and Milk Products

Type of Milk	Weight 1 Cup (g)	Average Percentage	Grams/Cup
Whole milk	244	4.7	11.5
Reduced fat milk (2%)	245	4.7	11.5
Low-fat milk (1%)	245	5	12.3
Nonfat milk	245	5	12.5
Chocolate milk	250	4.5	11.3
Evaporated milk	252	10.3	26.0
Sweetened condensed milk	306	12.9	39.5
Nonfat dry milk (unreconstituted)	120	51.3	61.6
Whole dry milk (unreconstituted)	128	37.5	47.9
Acidophilus milk (nonfat)	245	4.4	10.8
Buttermilk	244	4.3	10.5
Sour cream	230	3.9	8.9
Yogurt (plain)	277	4.4	10.0
Half-and-half	242	4.2	10.0
Light cream	240	3.9	9.3
Whipping cream	239	2.9	6.9

Source: National Dairy Council.

CONCLUSION

Milk is the first food of mammals. It contains major nutrients, carbohydrate, fat, and protein, with water being predominant (88%). The two major proteins in milk are casein and whey, with additional protein found in enzymes. The fat content of milk varies and is designated by law according to the specific product and jurisdiction.

Milk is pasteurized to destroy pathogens and is homogenized to emulsify fat and prevent creaming. Grade A milk must be treated in this manner if subjected to interstate commerce. Milk may be fluid, evaporated, condensed, dried, or cultured and made into butter, cheese, cream, ice cream, or a variety of other products. It is a potentially hazardous food due to its high protein, water activity, and neutral pH and must be kept cold.

GLOSSARY

Buttermilk, cultured: Pasteurized low-fat or nonfat milk to which bacteria are added to ferment lactose to the more acidic lactic acid that clots the casein in milk.

Casein: Primary protein of milk, colloidally dispersed.

Casein micelles: Stable spherical particles in milk containing α_s-, β-, and κ-casein and also colloidal calcium phosphate. The micelles are stabilized by κ-casein, which exists mainly at the surface; the α_s- and β-casein fractions are located mainly in the interior of the micelles.

Cheese: Coagulated product formed from the coagulation of casein by lactic acid or rennin; may be unripened or bacteria ripened; made from concentrated milk.

Churning: Agitation breaks fat globule membranes so the emulsion breaks, fat coalesces, and water escapes.

Coagulate: The formation of new cross-links subsequent to the denaturation of a protein. This forms a clot, gel, or semisolid material as macromolecules of protein aggregate.

Creaming: Fat globules coalesce (less dense than the aqueous phase of milk) and rise to the surface of unhomogenized, whole, and some low-fat milk.

Cultured: See "fermented."

Evaporated milk: Concentrated to remove 60% of the water of ordinary fluid milk; canned.

Fermented: (Cultured) enzymes from microorganisms or acid that reduce the pH and clot milk by breaking down the organic substrates to smaller molecules.

Fortified: Increasing the vitamin content of fresh milk to contain vitamins A and D to levels not ordinarily found in milk.

Homogenization: Dispersion of an increased number and smaller fat globules to prevent creaming.

Imitation milk: Resembles (looks, tastes like) the traditional product but is nutritionally inferior; contains no butterfat or milk products.

Lactose intolerance: Inability to digest lactose due to the absence or insufficient level of intestinal lactase enzyme.

Maillard reaction: The first step of browning that occurs due to a reaction between the free amino group of an amino acid and a reducing sugar; nonenzymatic browning.

Milk solids nonfat (MSNF): All of the components of milk solids except fat.

Milk substitute: Resembles (looks, tastes like) traditional product and is nutritionally equal; contains no butterfat (eg, filled milk).

Overrun: The increase in volume of ice cream over the volume of ice cream mix due to the incorporation of air.

Pasteurization: Heat treatment to destroy both pathogenic bacteria, fungi (mold and yeast), and most nonpathogenic bacteria.

Rennin: Enzyme from the stomach of milk-fed calves used to clot milk and form many cheeses.

Ripening: The time between curd precipitation and completion of texture, flavor, and color development in cheese. Lactose is fermented, fat is hydrolyzed, and protein goes through some hydrolysis to amino acids.

Sterilization: Temperature higher than that required for pasteurization, which leaves the product free from all bacteria.

Sweetened, condensed milk: Concentrated to remove 60% of the water, contains 40–45% sugar.

Total milk solids: All of the components of milk except for water.

Whey: Secondary protein of milk, contained in serum or aqueous solution; contains lactalbumins and lactoglobulins.

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PART IV

Fats

CHAPTER 12

Fat and Oil Products

INTRODUCTION

Fat is a principal component of the diet. It is enjoyed in the diet due to its *flavor/mouthfeel, palatability, texture*, and *aroma*. Fats also carry *the fat-soluble vitamins* A, D, E, and K. Sources of fats and oils may be animal, vegetable, or marine which may be manufactured in some combination in industrial processing. *Fats* appear solid at room temperature, whereas *oils* are liquid at room temperature.

Some fats are essential, such as linolenic and linoleic fatty acids, indicating that either the body *cannot* make them or cannot make *enough*. Fats and oils are *insoluble* in water and have a greasy feel that the consumer may feel or see evidence of on a napkin or dinner plate. Fats may be *processed* into monoglycerides and diglycerides—glycerol units that have one or two fatty acid chains, respectively, and they may be *added* to many food products functioning as emulsifiers.

Some of the functions of fat in food preparation are as follows:

- Add or modify flavor, texture
- Aerate (leaven) batters and doughs
- Contribute flakiness
- Contribute tenderness
- Emulsify (See Chapter 13)
- Transfer heat, such as in frying
- Prevent sticking
- Provide satiety

Oils used in margarines, spreads, dressings, retail bottled oils, as well as frying oils are the largest market segments of edible oils (1). Soybean oil is the highest volume vegetable oil used in the United States. It is incorporated into a variety of products.

Various fat replacements attempt to mimic fat in mouthfeel and perception so that it is good tasting and low-fat. Their caloric and cholesterol level are significantly *less* than fat. Fats and oils are not part of the composition of fruits, and many vegetables.

As a group, fats and oils should be used sparingly in the diet. *Fats and oils* are *triglycerides*, the *major* constituent of lipids. Overall, lipid is the umbrella term that includes the *triglycerides*, *phospholipids* and *sterols*.

STRUCTURE AND COMPOSITION OF FATS

Glycerides

Glycerides include *monoglycerides*, *diglycerides*, and *triglycerides*. The first two act as emulsifiers in foods, while the most abundant fatty substance in food—more than 95%—is the *triglycerides*. Triglycerides are insoluble in water and may be either liquid or solid at room temperature, with *liquid* forms generally referred to as *oils* and *solid* forms as *fats*.

Structurally, glycerides contain a glycerol molecule backbone joined to one or more fatty acid molecules. A *monoglyceride* contains glycerol esterified to *one* fatty acid molecule and the equation for that reaction is given in Figure 12.1 (the general formula for a fatty acid is used where R represents the hydrocarbon chain).

If *two* fatty acids are esterified to glycerol, a *diglyceride* is formed, and *three* fatty acids undergoing the same reaction make a *triglyceride*. If a triglyceride contains three *identical* fatty acids, it is called a *simple triglyceride*; if it contains two or three *different* fatty acids it is called a *mixed triglyceride*. Spatially, there is no room for all three fatty acids to exist on the same side of the glycerol molecule; thus, triglycerides are thought to exist in either a stair-step (chair) or a tuning-fork arrangement (Figure 12.2). The arrangement and specific type of fatty acids on the glycerol determine the chemical and physical properties of a fat.

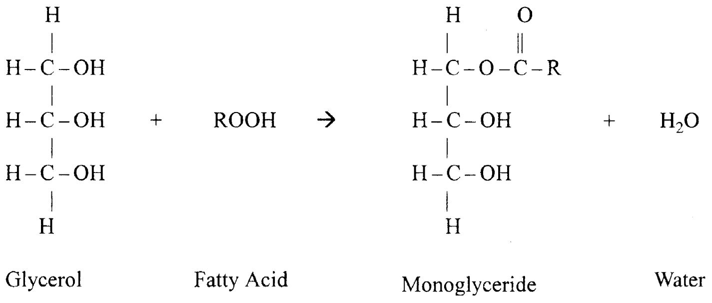


FIGURE 12.1 Formation of a monoglyceride.

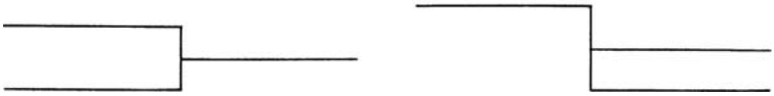


FIGURE 12.2 Fatty acid tuning-fork (left) and stair-step or chair arrangements (right).

Minor Components of Fats and Oils

In addition to glycerides and free fatty acids, lipids may contain small amounts of phospholipids, sterols, tocopherols, fat-soluble pigments, and vitamins, as discussed in this section of the text.

Phospholipids are similar to triglycerides but contain only *two* fatty acids esterified to glycerol. In place of the third fatty acid, there is a polar group containing phosphoric acid and a nitrogen-containing group, the most common is known as ***lecithin*** (Figure 12.3). Lecithin is found in nearly every living cell. The word is derived from the Greek *lekithos*, which means "yolk of an egg," and lecithin is in egg yolk. However, the primary *commercial* source of lecithin is the soybean (2).

The two fatty acids of a phospholipid are attracted to fat, whereas the phosphorus and nitrogen portions are attracted to water. Therefore, a phospholipid forms a bridge between fat and water, two ordinarily *immiscible* substances, and emulsification is observed (see Emulsification and Chapter 13). "Refined" lecithins are modified to provide important surface active properties to a variety of foods such as instant drink mixes, infant formulas, meat sauces and gravies, dispersible oleoresins, pan releases, chewing gum, and fat-replacer systems (2).

Sterols contain a common steroid nucleus, an 8–10 carbon side chain and an alcohol group. The chemists view of sterols is *unlike* triglycerides or phospholipids—sterols are round in shape. Cholesterol is the primary *animal sterol* (Figure 12.4) although *plant sterols*, or stanols, also exist; the most common ones are sitosterol and stigmasterol. Other plant sterols are found in "margarine"-type products, including those marketed under the trade name Benecol®.

Tocopherols are important minor constituents of most *vegetable oils*; *animal fats* contain *little or no* tocopherols. Tocopherols are antioxidants, helping to prevent oxidative rancidity and also are sources of vitamin E. They are *partially*

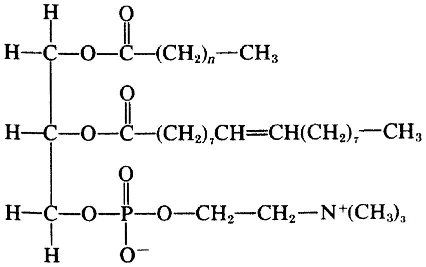


FIGURE 12.3 Lecithin (phosphatidyl choline).

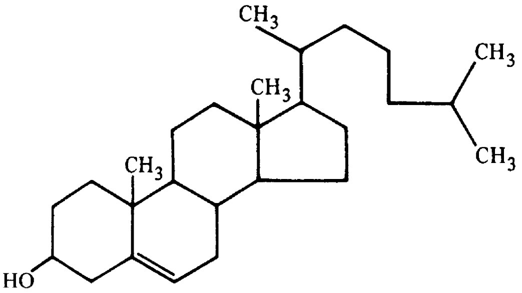


FIGURE 12.4 Cholesterol, phytosterols.

removed by the heat of processing and may be *added* after processing to improve oxidative stability of oils. If vitamin E is added to oil, for example, the oil frequently is marketed as a source of vitamin E or as an antioxidant-containing oil.

Fats are *not* good sources of vitamins, apart from vitamin E; however, fat-soluble vitamins A and D may be added to foods such as margarine and milk in order to increase nutritive value. Fat must be present in the diet for, among other reasons, the absorption of fat-soluble vitamins.

Pigments such as carotenoids and chlorophylls may be present in fats, and these may impart a distinct color to a fat. Such colors normally are removed by bleaching during processing (for example, in milk).

STRUCTURE OF FATTY ACIDS

Fatty acids are long hydrocarbon chains with a methyl group (CH_3) at one end of the chain and a carboxylic acid group (COOH) at the other. Most natural fatty acids contain from 4 to 24 carbon atoms and most contain an *even* number of carbon atoms in the chain. For example, butyric acid is the smallest fatty acid, having four carbon atoms, and it is found in butter; lard and tallow contain longer fatty acids. Fatty acids may be *saturated*, in which case they contain only single carbon-to-carbon bonds and have the general formula $CH_3(CH_2)_nCOOH$. They have a linear shape, as shown in Figure 12.5.

Fatty acids also may be *unsaturated*, containing one or more carbon-to-carbon double bonds. *Monounsaturated* fatty acids such as oleic acid contain only one double bond; *polyunsaturated* fatty acids, such as linoleic and linolenic acids, contain two or more double bonds. Generally, *unsaturated* fats are *liquid* at room temperature and have low melting points.

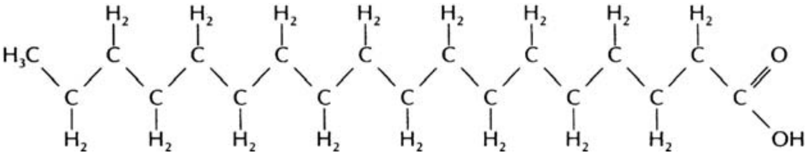
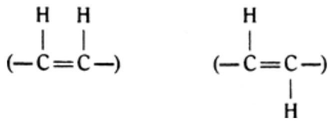


FIGURE 12.5 Example of a fatty acid.



$$(-\overset{\displaystyle H}{\overset{|}{C}}=\overset{\displaystyle H}{\overset{|}{C}}-) \qquad (-\overset{\displaystyle H}{\overset{|}{C}}=\underset{\displaystyle H}{\underset{|}{C}}-)$$

FIGURE 12.6 *Cis* (left) and *trans* (right) configurations representing isomeric structures of fatty acids.

The double bonds in fatty acids occur in either *cis* or the *trans* configuration (Figure 12.6), representing different isomeric structures. In the ***cis*** form, the hydrogen atoms attached to the carbon atoms of the double bond are located on the *same* side of the double bond. In the ***trans*** configuration of the isomer, the hydrogen atoms are located on *opposite* sides of the double bond, across from one another.

The *configuration* of the double bonds affects both melting point and shape of a fatty acid molecule. The *trans* double bonds have a *higher* melting point than the *cis* configurations and *trans* configurations do *not* significantly change the linear shape of the molecule. However, a *cis* double bond causes a *kink* in the chain. (A *cis* double bond introduces a bend of about 42° into the linear hydrocarbon chain.) Such kinks affect some of the properties of fatty acids, including their melting points.

All naturally occurring fats and oils that are used in food exist in the *cis* configuration. However, *hydrogenation* of oils causes conversion of some double bonds to the *trans* configuration (see Trans Fat), and thus some *trans* fats may be used in food. The National Cholesterol Education Program (NCEP) has stated that "*trans* fatty acids are another LDL-raising fat that should be kept to a low intake." Specific labeling that includes *trans* fatty acids content has been desired by some nutrition activists (3). It is now the law. Effective January 2006, Nutrition Facts food labels and advertisements *include* data on *trans* fatty acids.

Isomerism

Fatty acids may have geometric or positional ***isomers***, which are *similar* in number of C, H, and O, but form *different* arrangements, thus offering different chemical and physical properties. Oleic and elaidic acids are examples of *geometric* isomers, existing in the *cis* and *trans* forms, respectively. *Positional* isomers have the same chemical formula; however, the *position* of the double bonds varies. Examples include alpha-linolenic acid, which has double bonds at carbons 9, 12, and 15, counting from the acid end of the chain, and the rare isomer gamma-linolenic acid, which has double bonds at positions 6, 9, and 12.

Commercial *modification* of fats may produce *either* geometric or positional isomers. Geometric isomers tend to be produced during hydrogenation of fats and positional isomers may be formed during interesterification or rearrangement of fats.

NOMENCLATURE OF FATTY ACIDS

Fatty acids are named in three ways, (1) each has a *common* or *trivial* name, which has been used for many years, and they also have (2) a *systematic* or *Geneva* name, which is more recent and has the advantage of describing the structure of the fatty acid to which it belongs. In addition, there is (3) the *omega* system, which classifies fatty acids according to the position of the first double bond, counting from the methyl end of the molecule. This system was developed to classify families of fatty acids that can be synthesized from each other in the body. Examples of all three names for some of the most common fatty acids are given in Table 12.1.

Fatty acids also are denoted by two numbers, the first signifying the number of carbon atoms in the chain and the second indicating the number of double bonds present. For example, oleic acid, which contains 18 carbon atoms and 1 double bond, could be written as 18:1 (Table 12.1).

Geneva or Systematic Nomenclature

The Geneva naming system is a systematic method of naming the fatty acids, and each name completely describes the structure of the fatty acid to which it belongs. Each unsaturated fatty acid is named according to the number of carbon atoms in the chain, as shown in Table 12.1. For example, stearic acid, which has 18 carbon atoms in its chain, has the name octadecanoic acid; **octadec** means 18. The *-oic* ending signifies that there is an acid group (COOH) present, and

TABLE 12.1 Nomenclature of Some Common Fatty Acids

Systematic Name	Common Name	No. of Carbons	Melting Point °F (°C)
Ethanoic	Acetic	2	
Butanoic	Butyric	4	18 (−7.9)
Hexanoic	Caproic	6	26 (−3.4)
Octanoic	Caprylic	8	62 (16.7)
Decanoic	Capric	10	89 (31.6)
Dodecanoic	Lauric	12	112 (44.2)
Tetradecanoic	Myristic	14	130 (54.4)
Hexadecanoic	Palmitic	16	145 (62.9)
Octadecanoic	Stearic	18	157 (69.6)
Eicosanoic	Arachidic	20	168 (75.4)
Docosanoic	Behenic	22	176 (80.0)
9-Octadecenoic	Oleic	18–1	61 (16.3)
9,12-Octadecadienoic	Linoleic omega-6	18–2	20 (−6.5)
9,12,15-Octadecatrienoic	Linolenic omega-3	18–3	9 (−12.8)

Source: Adapted from Institute of Shortening and Edible Oils.

anoic signifies that there are no double bonds in the chain. Palmitic acid, which contains 16 carbon atoms, is named hexadecanoic acid. **Hexadec** means 16 and the **anoic** ending again shows that there are no double bonds in this fatty acid chain (the **oic** equals presence of an acid group).

Fatty acids that contain double bonds also are named according to the number of carbon atoms they contain. Therefore, oleic acid (18:1), linoleic acid (18:2), and linolenic acid (18:3) all have **octadec** as part of their name, signifying that they each contain 18 carbon atoms. The rest of the name differs, however, because they contain one, two, or three double bonds, respectively. The number of double bonds and their position in the fatty acid chain are both specified in the name.

It is important to note that the position of each double bond is specified counting from the functional group or **acid end** of the molecule, *not* from the methyl end. Thus, oleic acid has the name 9-octadecenoic acid. The number 9 refers to the position of the double bond between carbon-9 and carbon-10, counting from the acid end. Note that the name ends with **enoic** acid, the **en** signifying that there is a double bond present.

Linoleic acid is named 9,12-*octadecadienoic* acid. Again, the position of double bonds is specified, counting from the acid end. **Octadeca** means that there are 18 carbon atoms in the chain and **dien** signifies that there are two double bonds in the chain. Similarly, linolenic acid, which contains three double bonds, is named 9,12,15-*octadecatrienoic* acid. The letters **trien** indicate that there are three double bonds in the chain and again their positions are specified counting from the acid end of the molecule.

The configuration of the double bonds also may be specified in the name. For example, oleic acid and elaidic acid are geometric isomers, because the double bond in oleic acid exists in the *cis* configuration, whereas elaidic acid contains a double bond in the *trans* configuration. The complete name for oleic acid is ***cis*, 9-octadecenoic acid** and elaidic acid is named ***trans***, **9-octadecenoic acid**.

By looking at a systematic name for a fatty acid, it is possible to tell how many carbon atoms it contains and how many double bonds and where they are located. Each name gives important information about the fatty acid that is not available just by looking at the trivial or omega name of the acid.

The Omega Naming System

The omega naming system is used for unsaturated fatty acids and denotes the position of the first double bond in the molecule, counting from the **methyl** (CH_3) end, not the acid (as in the Geneva system). This is because the body lengthens fatty acid chains by adding carbons at the acid end of the chain. Using the omega system, a family of fatty acids can be developed that can be made from each other in the body. For example, an omega-6 fatty acid contains its first double bond between carbon-6 and carbon-7, counting from the methyl end. Linoleic acid is an example of an omega-6 fatty acid and it is the primary member of the omega-6 family. Given linoleic acid, the body can add two carbon atoms to make arachidonic acid (20:4), which also is an omega-6 fatty acid.

The primary omega-3 fatty acid is linolenic acid, which contains three double bonds. The first double bond is located on carbon-3, counting from the methyl end. The body can synthesize both eicosapentaenoic acid (EPA: 20:5) and docosahex-aenoic acid (DHA: 22:6) from linolenic acid. Both EPA and DHA are omega-3 fatty acids, because their first double bond is located at carbon-3 (again, counting from the methyl end of the molecule).

PROPERTIES OF FATS AND OILS

Crystal Formation

When liquid fat is cooled, the molecular movement slows down as energy is removed and the molecules are attracted to each other by Van der Waals forces. These forces are weak and of minor significance in small molecules. However, their effect is cumulative, and in large or long-chain molecules, the total attractive force is appreciable. Consequently, fat molecules can align and bond to form crystals.

Symmetrical molecules and molecules with fatty acids that are similar in chain length align most easily to form crystals. Fats containing *asymmetrical* molecules and molecules containing kinks due to double bonds align less easily, because they cannot pack together closely in space. Molecules that align easily need less energy to be removed before they will crystallize, and so they have high melting points. They also tend to form *large* crystals. Molecules that do not align easily have low melting points, because more energy must be removed before they crystallize and they tend to form *small* crystals.

Polymorphism

Fats can exist in different crystalline forms, and this phenomenon is known as ***polymorphism***. A fat may crystallize in one of four different crystal forms, depending on the conditions during crystallization and on the composition of the fat. The smallest and least stable crystals are called **alpha** (α) **crystals**. These are formed if fats are chilled rapidly. The alpha crystals of most fats are unstable and change readily to **beta prime** (β′) **crystals**. These are small needellike crystals, approximately 1 μm long. Fats that can form stable β-crystals are good for use as shortenings, as they can be creamed easily and give a smooth texture. Unstable β′ crystals change to the **intermediate crystal** form, about 3–5 μm in size, and finally convert to **coarse beta** (β) **crystals**, which can range from 25 to 100 μm in length. Beta crystals have the highest melting point.

Formation of small crystals is favored by rapid cooling with agitation. This allows formation of many small crystals, instead of slow growth of fewer large crystals. (Smaller crystals are desirable if a fat contributes aeration to a food.) Growth of large crystals occurs if cooling is slow.

The more heterogeneous the fat, the more likely that the molecules form small stable crystals. Homogeneous fats readily form large crystals. Lard is an example of a homogeneous fat; more than 25% of the molecules contain stearic acid, palmitic acid, and one unsaturated fatty acid molecule (usually oleic acid). Therefore, lard exists in the coarse *beta* crystalline form. However, lard can be modified by interesterification, which causes the fatty acids to migrate and recombine with glycerol in a more random manner. Rearranged lard forms stable β'-crystals, because it is more heterogeneous. Acetoglycerides are able to form stable α-crystals, because they contain acetic acid esterified to glycerol in place of one or two fatty acids. This increases the heterogeneity of the fatty acid composition of each individual triglyceride, which hinders the formation of large crystals.

All other things being equal, a fat with small crystals contains many more crystals and a much greater total crystal surface area than does a fat containing large crystals. Fats with small crystals are harder fats, have a smooth, fine texture, and appear to be less oily because the oil is present as a fine film surrounding the crystals, whereas the reverse is true of fats with large crystals.

The food industry uses controlled polymorphism to obtain fats with crystal sizes that improve their functional properties in foods. For example, fats used for creaming must contain small, stable crystals in the β' form; thus, crystallization is controlled during the manufacturing process.

Melting Points

The melting point is an index of the force of attraction between molecules. The greater the attractive forces between molecules, the more easily they will associate to form a solid and the harder it is to separate them when they are in the crystalline form and convert them to a liquid. A lot of energy in the form of heat must be put in to convert a solid to a liquid; thus, the melting point will be high. In other words, a high melting point indicates a strong attractive force between molecules. A strong attractive force indicates a good degree of fit between the molecules. Molecules that do not fit together well do not have strong attractive forces holding them together, and so they have lower melting points.

A fat or oil, which is a mixture of several triglycerides, has a lower melting point and a broader melting range than would be expected based on the melting points of the individual components. However, the *melting range* is dependent on the fatty acids of the component triglycerides. Fats also may be plastic at room temperature, containing some triglycerides that are liquid and some that are solid.

Generally speaking, oils liquid at room temperature tend to be more unsaturated, have shorter chains, and have lower melting points than fats, which are plastic or solid, with long chains and high melting points at room temperature. However, this is not always the case, as illustrated by coconut oil (see Tropical Oils), which has a high level of saturates (90%), but a low *melting range* [75–80 °F (24–27 °C)]. It is liquid at room temperature because it contains an appreciable number of relatively short-chain (12 carbons) fatty acids, as is the case with palm and palm kernel oils. Lard, on the other hand, contains only about 37% saturates, but mostly long-chain fatty acids, and so it is semisolid at 80 °F (27 °C).

As mentioned, the melting point of a fat or oil is actually a range, not a sharply defined temperature. The melting range depends on the composition of the fat. Each fat or oil contains triglycerides that melt at different temperatures, depending on their component fatty acids. Some fats have a wide melting range, whereas others, such as butter or chocolate, have a narrow melting range. Chocolate has a narrow melting range that is close to body temperature, and this accounts for its characteristic melt-in-your-mouth property.

The melting points of individual fatty acids depend on such factors as *chain length, number of double bonds* (degree of saturation), and *isomeric configuration*, because all these factors affect the degree of fit and the force of attraction between fatty acid molecules.

Chain length. *Long-chain* fatty acids have a higher melting point than *short-chain* fatty acids, because there is more potential for attraction between long chains than there is between short chains. The attractive forces are cumulative and can be appreciable if the chain is long enough. (In other words, you can think of them as having a zipper effect. A long zipper is much stronger than a short one, because more teeth are intersecting with each other.) For example, butyric acid (4:0) has a melting point of 18°F (−7.9°C), whereas stearic acid (18:0) has a higher melting point of 157°F (69.6°C). Stearic acid is a crystalline solid at room temperature, whereas butyric acid is a liquid unless the temperature drops below the freezing point of water.

Number of double bonds. A second factor that determines melting point is the *number of double bonds*. As the number of double bonds *increases*, the melting point decreases. Double bonds introduce kinks into the chain and it is harder for molecules to fit together to form crystals; thus, the attractive forces between the molecules are weaker. This is demonstrated by comparing the melting points of stearic, oleic, linoleic, and linolenic acids, as shown in Table 12.1.

Isomeric configuration. A third influence on melting point is *isomeric configuration*. Geometric isomers have different melting points, because the *cis* double-bond configuration introduces a much bigger kink into the molecule than does the *trans* configuration. Consequently, the *cis* isomer has a lower melting point than the *trans* isomer, because molecules in the *cis* configuration do not fit together as well as molecules in the *trans* configuration. This can be seen by comparing the melting points of oleic and elaidic acids. Oleic acid (*cis*) has a lower melting point than elaidic acid (*trans*). Low-*trans* liquid shortening such as the high oleic, monounsaturated sunflower oil require no *trans* or “hydrogenated” reporting on labels, because it has a level of less than 2% *trans* fatty acids. A standard shortening may contain more than 30% *trans* fat levels.

The melting point of a triglyceride depends on the melting point of the component *fatty acids* as discussed above. *Simple* triglycerides can fit together easily, because the three fatty acid chains are identical, and therefore allow for close packing of the molecules and high melting points. In general, the more *heterogeneous* triglycerides will not fit together as well, and so will have lower melting points. The melting point of a fat increases with each shift in polymorphic form, from alpha to coarse beta crystals.

Plastic Fats

Fats may either be liquid, solid, or plastic at room temperature. A ***plastic fat*** is moldable because it contains both *liquid* oil and *solid* crystals of triglycerides. Its consistency depends on the *ratio* of solid to liquid triglycerides: the more *liquid* triglycerides, the *softer* the fat will be, and the more *solid* triglycerides, the *harder* it will be. A plastic fat is a two-phase system, containing solid fat crystals surrounded by liquid oil. The liquid phase acts as a lubricant, enabling the solid crystals to slide past one another, and thus conferring moldability to the fat. A fat that contains only solid triglycerides is hard and brittle and cannot be molded, because the crystals cannot move past each other.

CULINARY ALERT! Fats that are "creamed" as per a recipe set of instuction (for some cookies or shortened cakes) must be plastic, so that they are easily workable and incorporate air into a mixture without breaking.

Ideally, plastic fats should be semisolid or plastic over a *wide* temperature range, so that creaming can be carried out at different (high or low) temperatures. Fats with a wide plastic range contain some triglycerides that are *solid* at high temperatures and some triglycerides that are *liquid* at low temperatures.

Fats with a *wide* plastic range are obtained by commercial modification, including the processes of hydrogenation and interesterification. Examples of such fats include *partially hydrogenated* soybean oil (found in margarine) and *interesterified lard*. Shortenings that are to be creamed also must contain small crystals, preferably in the β' form. Rearranged lard forms stable β'-crystals, and so has a fine-grained texture that is suitable for creamed fats.

Butter has a *narrow* plastic range, and therefore, is *not* a good choice for a fat that needs to be creamed. It cannot be creamed if taken straight out of the refrigerator, because it is too hard; nor can it be creamed if it sits on the counter on a warm day, because it will be too liquid.

COMPOSITION OF DIETARY FATS AND OILS

A table showing fatty acid composition of various fats and oils frequently used by the consumer in food preparation is shown in Figure 12.7.

Polyunsaturated fats are liquid at room temperature and found primarily in *plants*. Safflower oil is 76% polyunsaturated, sunflower oil is 71%, soybean oil 54%, and corn oil 57% ("partially hydrogenated" oils are hydrogenated to have a *greater* degree of saturation).

Monounsaturated fats are liquid at room temperature and found chiefly in *plants*. Olive oil is 75% monounsaturated, high-oleic safflower oil is 80% (versus 76% polyunsaturated safflower oil) and canola (rapeseed oil) is 61% monounsaturated. These fats are associated with a *decrease* in serum cholesterol and a decreased risk of coronary heart disease (CHD).

Dietary Fat	Fatty acid content normalized to 100 %			
	Saturated Fat	Polyunsaturated	Alpha Linoleinc	Monounsaturated Fat
Canola oil	7%	21%	11%	61%
Safflower oil	10%	76%	Trace	14%
Sunflower oil	12%	71%	1%	16%
Corn oil	13%	57%	1%	29%
Olive oil	15%	9%	1%	75%
Soybean oil	15%	54%	8%	23%
Peanut oil	19%	33%	Trace	48%
Cottonseed oil	27%	54%	Trace	19%
Lard*	43%	9%	1%	47%
Beef tallow*	48%	2%	1%	49%
Palm oil	51%	10%	Trace	39%
Butterfat*	68%	3%	1%	28%
Coconut oil	91%	-	2%	7%

*Cholesterol content (mg/Tbsp): Lard 12; beef tallow 14; butterfat 33.
(No cholesterol in any vegetable-based oil.)

Alpha-Linolenic Acid (an Omega-3 Fatty Acid)

Source: POS Pilot Plant Corporation, Saskatoon, Saskatchewan, Canada June 1994

Canola Council of Canada, 400·167 Lombard Avenue, Winnipeg Manitoba Canada R3B OT6

FIGURE 12.7 Comparison of composition of dietary fat (*Source*: Canola Council of Canada).

Saturated fats are solid at room temperature and found primarily in *animals*, although they are found in some tropical oils (see below). These fats are implicated in a *greater* rise in serum cholesterol than dietary cholesterol!

As shown above, it is not a simple categorization of the type of fatty acids that either raise, lower, or show no effect on serum cholesterol. More is described below regarding saturated fats.

Animal fats typically have 18 carbons in the fatty acid chain. These long chains are made of various fatty acids and are chiefly *saturated*. Such fats may be *rendered* for use in baking and cooking applications (see Rendered Fat). Animal fats derived from hogs and cattle include the following:

- **Lard**. Rendered from hogs, 43% saturated fatty acids. It lacks natural antioxidants, and therefore is less stable than equally saturated vegetable oils that have been partially hydrogenated (4).
- **Tallow (suet)**. Rendered from cattle, 48% saturated fatty acids.

Tropical oils are derived from plants grown in tropical areas of the world. Unlike most plants, these in particular are high in saturated fat content and contain an appreciable amount of short-chain fatty acids. Examples of tropical oils include the following:

- **Cocoa butter**. Extracted from cocoa beans, typically used in candies and chocolate confections.
- **Coconut oil**. Highest saturated fat vegetable oil—over 90% saturated; very stable against oxidation and to a lesser degree stable against hydrolysis.
- **Palm oil**. Fifty percent saturated fatty acids; stable against oxidation.
- **Palm kernel oil**. Eighty-four percent saturated fatty acids; derived from the kernel of the palm tree; stable against oxidation.

CULINARY ALERT! In part due to the fact that animal fats contain cholesterol, saturated fat, and a pronounced flavor, the use of lard and tallow in foods has declined in favor of vegetable oils.

PRODUCTION AND PROCESSING METHODS

Crops are bred to increase the grower's yield while offering health benefits to *consumers* who want desirable health features in fats and oils. Both groups desire shelf stability. A brief discussion of the *conventional* as well as *nonconventional* approaches to breeding appears in the following text. Techniques are provided by the molecular geneticist and are available to growers and oilseed processors so that suppliers of edible oils can make both shelf stability *and* consumer health their priorities.

For example, *ordinary* soybean oil is *not* shelf stable because it contains 7.6% linolenic acid, an unstable, 18–3, polyunsaturated fatty acid. To improve on this, *conventional* cross-breeding and selection has developed a low-linolenic soybean oil (LLSO) containing 2.5–3% linolenic content (5). This lower-linolenic soybean oil derived from selected soybeans is more stable than ordinary soybean oil and does not require hydrogenation for protection against rancidity. Consumers who want *less* saturated oil may make this oil their choice.

Unconventional approaches to breeding include gene modification, which produces a more stable oil that does not require hydrogenation. Then, stability as well as lower saturated fat may be achieved in a product. So, either conventional cross-breeding or unconventional genetic modification offers increased shelf stability without loss of health benefits, and this may be desirable.

Deodorized Oils

Deodorized oils are those that have undergone the process of removing odors by heat and vacuum or by adsorption onto charcoal. For example, olive oil may be deodorized to provide broader use in *baking* applications, without imparting its characteristic odor and flavor to food.

Rendered Fat

Rendered fat is the solid, usable fat derived from animal fat after it is heated and freed from connective tissue, then cooled. Food manufacturers render *hog* fat and process it to become *lard*, or *cattle* fat to become *tallow*. On a small scale, the consumer renders fat by (1) cutting an animal into small pieces and gently boiling the pieces to extract liquid fat, and then (2) cooling, until it becomes solid. The leftover rind, devoid of usable fat, has uses outside the scope of this discussion of fats.

As previously mentioned, lard and tallow are not as commonly used in cooking as they were in the past, partially because of the pronounced flavor, saturated fat, and cholesterol content. As well, animals are now bred to be leaner, so lard is less available. Today, there are many convenient, commercially prepared shortenings on the market that replace lard in cooking.

The large crystalline structure of lard is composed of many similar triglycerides that are used to produce a highly desirable, flaky pie crust. Lard may be processed to contain smaller crystals, and then it functions more like a hydrogenated shortening. The addition of antioxidants such as BHA and BHT protect it against rancidity.

MODIFICATION OF FATS

Hydrogenation

Hydrogenation is the process of adding hydrogen to *un*saturated fatty acids to reduce the number of double bonds. The purpose of hydrogenation is twofold:

- To convert liquid oils to semisolid or plastic fats
- To increase the thermal and oxidative stability of the fat, and thus the shelf life

Hydrogenation of unsaturated fatty acid occurs when *hydrogen gas* is reacted with *oil* under controlled conditions of *temperature* and *pressure*, and in the presence of a nickel, copper, or other *catalyst*. The reaction is carefully controlled and stopped when the desired extent of hydrogenation has been reached. As the reaction progresses, there is a gradual production of *trans* fatty acids that increases the melting point of the fat or oil and creates a more solid product. Shortening is hydrogenated oil.

The extent of the hydrogenation process is controlled to achieve stability and/or the physical properties required in the finished food. If the reaction is taken to completion, a *saturated* fat is obtained and the product is hard and brittle at room temperature. However, this is not usually the aim of hydrogenation, as *partial* hydrogenation normally is desired, providing an *intermediate* degree of solidification, reducing the number but not eliminating all double bonds. In fact, approximately 50% of the total fatty acids present in *partially hydrogenated vegetable shortening* products are *mono*unsaturated and about 25% are *poly*unsaturated.

These polyunsaturated fats are subject to oxidative rancidity. Thus, reducing the number of double bonds by hydrogenation increases their stability. Once saturated, consumption of the fat intake contributes more toward the elevation of serum cholesterol than does dietary cholesterol intake.

The process of hydrogenation causes conversion of some *cis* double bonds to the *trans* configuration. Most of the *trans* fatty acids formed are monounsaturated. Tub margarines, for examples, typically contain *trans* fatty acid at levels of 13–20%.

A previous *Federation of American Societies for Experimental Biology (FASEB)* report published in 1985 (6) concluded that there was little cause for concern with the safety of dietary *trans* fatty acids, both at present and expected levels of consumption. However, this was challenged by later research, which indicated that a high *trans* fatty acid diet raised total and LDL cholesterol (low-density lipids, or "bad" cholesterol) levels and lowered HDL cholesterol (high density lipids, or "good" cholesterol) levels in humans.

"Scientific evidence shows that consumption of saturated fat, *trans* fat, and dietary cholesterol raises low-density lipoproteins (LDL), or "bad" cholesterol levels which increases the risk of coronary heart didease (CHD)" (FDA). Although saturated fat is the main culprit that raises LDL, *trans* fat and dietary cholesterol also contribute significantly (FDA).

"A small amount of *trans* fat is found naturally, primarily in dairy products, some meat, and other animal-based foods" (FDA). The majority is formed when manufacturers add hydrogen to turn liquid oils into partially/hydrogenated oils. Thus, *trans fat can* be found in hydrogenated vegetable shortenings, some margarines (not butter), crackers, snack items, and convenience fast food. The advice is to read labels, since many food products have been reformulated with passage of new labeling mandates. *Frito-Lay* is one example of a company that early reformulated its line of chips to eliminate *trans* fats prior to the labeling requirement. Specifically, Frito's® and Lay's® products contain zero *trans* fats.

Plastic fats have useful functional properties for use in margarines or shortenings that are to be creamed. Hydrogenated fats frequently are specified in batter and dough recipes that depend on the creaming ability of solid fats for aeration (Chapter 14). Creaming increases volume by incorporating air and results in numerous air cells. As a result, the grain of the crumb in baked products is small and even.

Interesterification

Interesterification, or ***rearrangement***, causes the fatty acids to migrate and recombine with glycerol in a more random manner. This causes new glycerides to form and *increases* the *heterogeneity* of the fat. However, it does *not* change the degree of unsaturation or the isomeric state of the fatty acids.

Lard is an example of a fat that is modified in this way to improve its functional properties. In its natural state, lard is a relatively *homogeneous* fat, as has already been mentioned. Therefore, it has at *narrow* plastic range and is *too firm* to be used straight from refrigerator but *too soft* at temperatures above normal room temperature. Lard also contains coarse β-crystals. Rearrangement increases the *heterogeneity* of lard, enabling it to form stable β′-crystals and *increasing* the temperature range over which it is plastic or workable. This significantly enhances its use as a shortening product.

Hydrogenation may be used in conjunction with interesterification and may either precede or follow it. This gives a shortening manufacturer the ability to produce fats with a *wide* range of properties.

Acetylation

Acetoglycerides or ***acetin fats*** are formed when one or two fatty acids in a triglyceride are replaced by acetic acid (CH_3COOH). Acetin fats may be liquid or plastic at room temperature depending on the component fatty acids. However, the presence of acetic acid lowers the melting point of the fat, because the molecules do not pack together as readily. It also enables the fat to form stable α-crystals.

Acetin fats are used as edible lubricants; they also form flexible films and are used as coating agents for selected foods such as dried raisins and produce to prevent moisture loss (Chapter 17).

Winterization

Winterized oil is oil that has been *pretreated* to control undesirable cloudiness. The large, high-melting-point triglyceride crystals in oil are subject to crystallization (forming solids) at refrigeration temperatures. Therefore, in the process of winterization, oil is refrigerated and subsequently filtered to remove those large, undesirable crystals, which could readily disrupt a salad dressing emulsion. The treated oil is called *salad oil*, which is used specially in salad dressing.

CULINARY ALERT! *Salad oils* are clear and are bleached, deodorized, and refined, in addition to undergoing winterization. Salad oils differ from *cooking oils*, the latter of which do not undergo winterization.

DETERIORATION OF FATS

Fats deteriorate either by absorbing odors or by becoming *rancid*. Both of these are described below. For example, deterioration by *absorbing odors* becomes evident when *chocolate fat* absorbs the odor of (1) smoke in a candy store environment, or (2) soap packaged in the same grocery bag at the supermarket. Butter also may deteriorate by readily absorbing *refrigerator* odors. When *rancidity* causes deterioration, it produces a disagreeable odor and flavor in fatty substances.

CULINARY ALERT! Processing does not remove *all* chance of fat and oil deterioration and rancidity, but it prolongs the life of a fat or oil.

Deterioration by rancidity may occur in two ways (details below) making fats undesirable for use in foods. One way is ***hydrolytic rancidity***, which involves reaction of fats with water and liberation of free fatty acids. The other, ***oxidative rancidity***, is a more complex and potentially more damaging reaction. In this second case, the fat is oxidized and decomposes into compounds with shorter carbon chains such as fatty acids, aldehydes, and ketones all of which are volatile and contribute to the unpleasant odor of rancid fats.

Hydrolytic Rancidity

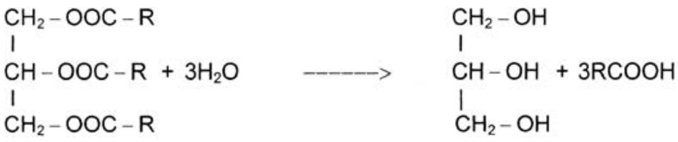
Fats may become rancid by hydrolytic rancidity when the triglycerides react with water and free their fatty acids from glycerol. The reaction is shown in Figure 12.8. If one molecule of water reacts with a triglyceride, *one* fatty acid is liberated and a *di*glyceride remains. To liberate glycerol, *all three* fatty acids must be removed from the molecule. The reaction is catalyzed by heat and by enzymes known as lipases. Butter contains lipase and if left on the kitchen counter on a warm day, a characteristic rancid smell frequently develops due to liberation of the short-chain butyric acid. (Unlike long-chain fatty acids, these short-chain fatty acids may form an unpleasant odor and flavor.)

Hydrolytic rancidity also is a problem with deep-fat frying, where the temperature is high and wet foods often are introduced into the hot fat. The continued use of rancid oil results in additional breakdown of the oil. To avoid this type of rancidity, fats should be stored in a cool place and if possible lipases should be inactivated.

CULINARY ALERT! Fats should be kept away from water and foods to be fried should be as dry as possible before they are added to hot fat. The kind of fat used for frying should be selected based on stability.

Oxidative Rancidity or Autoxidation

Oxidative rancidity is the *predominant* type of rancidity. In this process, the unsaturated fatty acids are subjected to oxidative rancidity or autoxidation. The *more* double bonds there are, the *greater* the opportunity for addition of oxygen to double bonds, increasing the risk that the fat or oil will become rancid. ***Autoxidation*** is complex and is promoted by heat, light, certain metals (iron and



$$\begin{array}{l} CH_2-OOC-R \\ | \\ CH-OOC-R\ +\ 3H_2O \\ | \\ CH_2-OOC-R \end{array} \quad \text{------->} \quad \begin{array}{l} CH_2-OH \\ | \\ CH-OH\ +\ 3RCOOH \\ | \\ CH_2-OH \end{array}$$

Figure 12.8 Hydrolytic rancidity.

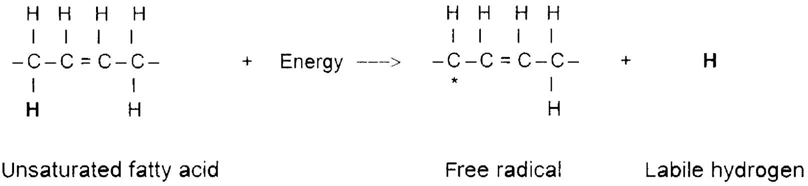


FIGURE 12.9 The initiation stage of autoxidation.

copper), and enzymes known as lipoxygenases. The reaction can be separated into three stages: initiation, propagation, and termination.

The **initiation stage** of the reaction involves formation of a free radical. A hydrogen on a carbon atom adjacent to one carrying a double bond is displaced to give a free radical, as shown in Figure 12.9. There is chemical activity around and in the double bonds. (The bold type indicates the atoms or groups of atoms involved in the reactions.) As previously mentioned, this reaction is catalyzed by heat, light, certain metals such as copper and iron, and lipoxygenases. The free radicals that form are unstable and very reactive.

The **propagation stage** follows the initiation stage and involves oxidation of the free radical to yield activated peroxide. This in turn displaces hydrogen from another unsaturated fatty acid, forming another free radical. The liberated hydrogen unites with the peroxide to form a hydroperoxide and the free radical can be oxidized as just described. Thus, the reaction repeats, or propagates, itself. Formation of one free radical, therefore, leads to the oxidation of many unsaturated fatty acids.

Hydroperoxides are very unstable and decompose into compounds with shorter carbon chains, such as volatile fatty acids, aldehydes, and ketones. These are responsible for the characteristic odor of rancid fats and oils. The two reactions of the propagation stage of autoxidation are shown in Figure 12.10.

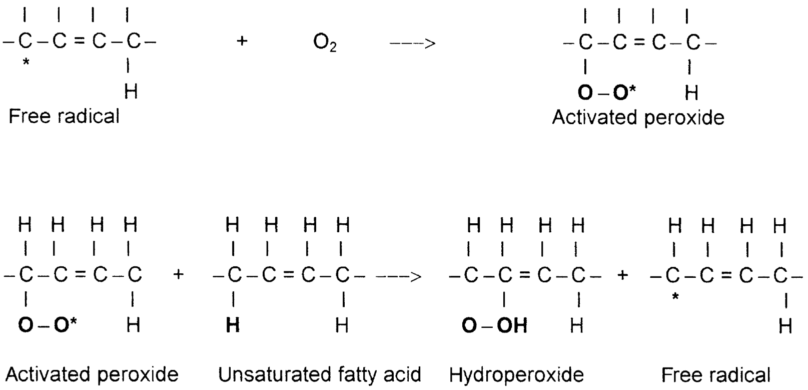


FIGURE 12.10 The two reactions of the propagation stage of autoxidation.

The **termination stage** of the reaction involves the reaction of free radicals to form nonradical products. Elimination of all free radicals is the only way to halt the oxidation reaction.

Prevention of Autoxidation

Oxidation can be prevented or delayed by *avoiding* situations that would serve as catalysts for the reaction. For example, fats and oils *must be stored* in a cool dark environment (offering temperature and light change controls) and in a closed container (to minimize oxygen availability). *Vacuum packaging* of fat-containing products controls oxygen exposure, and *colored glass* or wraps control fluctuations in light intensity. Fats also must be stored *away from metals* that could catalyze the reaction, and any cooking utensils used must be free of copper or iron. Lipoxygenases should be inactivated.

CULINARY ALERT! Store fats and oils in a cool dark environment and in a closed container. Colored glass jars or wraps control rancidity.

In addition, *sequestering agents* and *antioxidants* can be added to fats to prevent autoxidation, increasing keeping quality and shelf life of fats. (Chapter 17).

Sequestering agents bind metals, thus preventing them from catalyzing autoxidation. Examples of sequestering agents include EDTA (ethylenediaminetetraacetic acid) and citric acid.

Antioxidants help prevent autoxidation with its formation of fatty acid free radicals. Antioxidants prevent rancidity by donating a hydrogen atom to the double bond in a fatty acid and preventing the oxidation of any unsaturated bond. They halt the chain reaction along the fatty acid, which leads to rancidity.

Most antioxidants are phenolic compounds. Those approved for use in foods include ***BHA*** (butylated hydroxyanisole), ***BHT*** (butylated hydroxytoluene), ***TBHQ*** (tertiary-butyl hydroquinone), and propyl gallate. These are *all synthetic* antioxidants. The effectiveness of antioxidants may be increased if they are used together. For example, propyl gallate and BHA are more effective when *combined* than if used separately.

BHA is a waxy white solid that survives processing to create a stable product. It is effective in preventing oxidation of animal fats but not vegetable oils. BHT is a white crystalline solid that may be combined with BHA. It is effective in preventing oxidation of animal fats. TBHQ is a white-to-tan-colored powder that functions best in frying processes rather than baking applications (7).

Tocopherols are naturally occurring antioxidants that are present in vegetable oils. They can be added to both animal and vegetable oils to prevent oxidation. The tocopherols also are sources of essential nutrient vitamin E.

Use of antioxidants in foods containing fat increases their keeping quality and shelf life. Examination of food labels reveals that antioxidants are used widely in many food products, from potato chips to cereals. Without them, the quality of fat-containing foods would not be as good and off-flavors and odors due to oxidative rancidity would be commonplace.

SHORTENING AND SHORTENING POWER OF VARIOUS FATS AND OILS

Plant, animal, or numerous plant–animal blends of fats and oils may be used for shortening, and typically the blend is creamy. The shortening potential of a fat or oil is influenced by its fatty acid composition (see Figure 12.5), and various fats and oils may function as shortenings. "Shortenings" may include many types, from *pourable liquids to stiff solids*, with the latter being most commonly considered shortening. A shortening is hydrogenated oil and it functions to physically shorten platelets of protein–starch structure developed in manipulated wheat flour mixtures. Shortening power of some fats and oils appear below.

Lard has a large fatty acid crystal structure, unless it is interesterified. It forms a desirable flaky product. This solid fat when cut into pea-sized chunks or smaller melts within the gluten structure of flour, creating many layers or *flakes* in baked pie crusts or biscuits (more later)

Butter and margarine contain water and milk (20%) in addition to a variety of fat or oils (80%). One stick is derived from 2.5 quarts of milk. Due to this water, butter and margarine have less shortening potential than lard, hydrogenated shortening, or oil that contains 100% fat. When butter or margarine is incorporated into flour-based formulations, they toughen the mixture, as its water component hydrates the starch.

CULINARY ALERT! A recipe substituting butter or margarine for lard or hydrogenated shortening adds water; thus the recipe requires less additional water and yields a *less flaky* pie crust.

A replacement for butter originated in 1869 when margarine was formulated by a French pharmacist. Today, margarine may contain part cultured skim milk or whey, optional fat ingredient(s), emulsifier, and color (annatto or carotene) and may include added salt, flavoring, and vitamin A and D. The margarine is likely to be high in polyunsaturated fatty acids (PUFA) if oil is listed as the first ingredient on a margarine label. If *partially hydrogenated oil* is listed on a label as the first ingrdient, there is less PUFA. A product must be labeled "spread" if it does not meet the standard of identity for margarine. Also, today margarine *substitutes* may be milk-free, sodium-free, or even fat-free.

Hydrogenated fats are saturated and easily workable. When creamed, they incorporate air into a mixture. They are processed to be *without* a pronounced flavor and have a *wide* plastic range. Hydrogenated fats contain 100% fat and have greater shortening power than butter or margarine. Finished food products may be flaky; however, not as *flaky* as if lard is used.

Oils contain a *high* liquid to fat crystal ratio and are *un*saturated. They shorten strands of protein *mechanically* by coating the platelets. Oil controls gluten development and subsequent toughness because *less* water contacts the gluten proteins. Oil helps produce a *tender* product, but in pastries, *flakiness* may be sacrificed. Flakes are *not* readily obtained because there are no large chunks of fat to melt between layers of dough.

Tenderization versus Flakiness Provided by Fats and Oils

Lipids provide either ***tenderization*** or ***flakiness***, as discussed, and impart distinct characteristics of a food product. The differences are especially evident in finished pie crusts and also can be observed in biscuits. *Tender* products are easily crushed or chewed; they are soft and fragile, ie, oil pie crusts. *Flaky* products contain many thin pieces or layers of cooked dough, ie, puff pastry, lard pie crusts.

Some factors that affect these two distinct attributes are presented in Table 12.2. The *type of fat or oil* chosen to be incorporated into food, its *concentration, degree of manipulation*, and *temperature* each affect the flakiness and tenderness of a product. Fats and oils should be selected and used with knowledge of these factors. Yet, health attributes of a fat or oil may supersede other quality attributes creating products that do not meet traditional product

TABLE 12.2 Factors Affecting the Tenderness and Flakiness of a Product

The type of fat or oil—Chunks of solid fat create layers or flakes in the gluten starch mixture as they melt, whereas oil coats flour particles more thoroughly, creating less layers and a mealy product. Substituting one fat or oil for another may not produce acceptable or expected results.

Fat concentration—Fat may be reduced or omitted in a formulation or the fat that is used may not be 100% fat, it may be a butter, margarine, or "spread." Adequate levels of fat or oil must be present in foods if they are to meet acceptable standards. For example, sufficient fat in flour-based mixtures is needed to control gluten development and generate a tender crumb. Imitation "butters" or "spreads" have a high water content and may not have the high percentage of fat needed to perform satisfactorily in all baking, sautéing, or "buttering" processes.

Degree of manipulation—An insufficient degree of manipulation may result in poor distribution of fat throughout the food mixture. Inversely, excess manipulation may cause the fat to spread or be softened, thus minimizing the possibility of flakes. For example, a flaky pie crust is produced when solid fat is incorporated in the formulation as pea-sized chunks.

Temperature—Depending on the type of fat, cold shortenings (solid or liquid) provide less covering potential than room temperature shortenings and produce more flaky biscuits and pie crusts. Food items prepared with cold shortenings also remain slightly more solid in the hot oven while the item bakes. When a shortening is melted, it displays a greater shortening potential than an unmelted solid shortening; it coats better than the same amount of unmelted solid fat. Melted shortening produces a more tender, less flaky product.

standards. For example, for health reasons, a pie crust may not incorporate solid fat but may be prepared using oil. If that is the case, the finished pie crust will sacrifice flakiness but will be tender and crumbly.

CULINARY ALERT! In order to control formation of an undesirable crumbly food product, some gluten formation may be needed *prior* to the addition of the fat or oil. This may be achieved by adding fat to a recipe, *after* some hydration and manipulation has formed gluten.

EMULSIFICATION (SEE ALSO CHAPTER 13)

Fats and oils are *not* emulsifiers; however, in addition to providing flavor, aerating batters and doughs, shortening, fats, and oils are important *constituents* of emulsions. An emulsion consists of a three-phase system composed of (1) a ***continuous phase***—the phase or medium in which the dispersed phase is suspended, (2) a ***dispersed phase***—the phase that is disrupted or finely divided within the emulsion, and (3) an ***emulsifier***—the emulsifier is present at the interface between the dispersed phase and the continuous phase and keeps them apart. An emulsifier acts in the following ways:

- It adsorbs at the interface between two immiscible liquids such as oil and water.
- It reduces the interfacial tension between two liquids, enabling one liquid to spread more easily around the other.
- It forms a stable, coherent, viscoelastic interfacial film, which prevents or delays coalescence of the dispersed emulsion droplets.

Molecules that can act as emulsifiers contain both a polar, ***hydrophilic*** (water-loving) section, which is attracted to water, and a ***hydrophobic*** (or water-hating) section, which is attracted to hydrophobic solvents such as oil. In order for the hydrophilic section to be dispersed in the water phase and for the hydrophobic section to be dispersed in the oil phase, the molecule must adsorb at the *interface* between the two phases, instead of being dispersed in either bulk phase.

Good emulsifiers are able to interact at the interface to form a *coherent* film that does not break easily. Therefore, when two droplets collide, the emulsifier film remains intact and the droplets do *not* coalesce to form one big droplet. Instead, they drift away from each other.

The *best* emulsifiers are proteins, such as egg yolk (lipoproteins) or milk proteins, because they are able to interact at the interface to form stable films, and hence to form stable emulsions. However, many *other* types of molecules are used as emulsifiers.

Mono- and diglycerides are examples of emulsifiers that are added to products in order to provide ease of mixing. They adsorb at the interface, reducing ***interfacial tension*** and increasing the spreadability of the continuous phase, or the wettability of the dispersed phase.

In some cases, finely divided *powders* such as dry mustard or spices are used to act as emulsifiers in oil-in-water mixture. The mustard and spices adsorb at the interface and reduce interfacial tension. However, they *cannot* form a stable film around oil droplets, and so they are *unable* to form a stable emulsion. Therefore, they should *not* really be considered as emulsifiers.

Emulsions may be temporary or permanent. A *temporary emulsion* separates upon standing. The emulsion is not permanent because the hydrophobic oil and hydrophilic water components separate upon standing. This is because the emulsifiers used are unable to form a stable interfacial film to prevent coalescence of the droplets of the dispersed phase. As coalescence occurs, the droplets combine to form bigger ones, and eventually the two phases separate out completely. An example of a temporary emulsion would be French Dressing, which separates out a few seconds after it has been shaken.

A *permanent emulsion* is formed when two ordinarily nonmiscible phases, such as water and oil, are combined with an emulsifier. One phase (usually the oil phase) is dispersed within the other as small droplets. These remain dispersed in the continuous phase (usually water) because they are surrounded by a stable film of emulsifier that resists coalescence and so prevents separation of the two phases.

Thus, the time of separation of oil and water is dependent upon the effectiveness of an emulsifier and the degree of agitation. As mentioned, more detail on emulsification is provided in Chapter 13, but some examples of emulsified mixes are cake mixes, mayonnaise, and salad dressings.

Cake mixes contain an emulsifier that aids in incorporation of air upon stirring or beating. The emulsifiers are usually monoglycerides and diglycerides, which act by dispersing shortening in smaller particles. This creates a maximum number of air cells that *increase* cake volume and creates a more even grain in the baked product (Chapter 14).

Mayonnaise is an emulsified product. A real mayonnaise as opposed to salad dressing (mayo type) is described in the 1952 Standard of Identity. Mayonnaise is an emulsified semisolid, with not less than 65% by weight, edible vegetable oil.

Salad dressings are typically emulsified, containing oil, vinegar, water, salts, and so forth. Oil coats the salad contents and disperses herbs, spices, and other substances. Early application may *wilt* the salad due to salt in the dressing. Winterized oils are generally used. Some dressings are available in no-fat formulations. Others are available as low-calorie sprays. Except for bacon dressing, which uses bacon fat, *solid* fats generally are *not* acceptable for use in a dressing.

Hydrocolloids (see Fat Replacements, and Chapter 5) such as gelatin, gums, pectin, and starch pastes may be added in the preparation of salad dressings, but they contain only a hydrophilic section and are not considered emulsifiers. Rather, they act as stabilizers in emulsions and help to prevent or lessen coalescence, because they increase the viscosity of the continuous phase.

FRYING

Frying with melted fat or oil is a common cooking technique because frying is a *rapid* heat transfer method that achieves a *higher* temperature than boiling or dry heat temperature. The characteristics of fats for frying include that the fat must be colorless, odorless, and bland and have a high smoke point.

Smoke Point

The ***smoke point*** is the temperature at which fat may be heated before continuous puffs of blue smoke come from the surface of the fat under controlled conditions. The presence of smoke indicates that free glycerol has been further hydrolyzed to yield *acrolein*, a mucous membrane irritant. Monoglycerides in hydrogenated shortenings and diglycerides are hydrolyzed more easily than triglycerides and they tend to have a low smoke point. Therefore, they are not recommended in frying oils.

When fat *exceeds* the smoke point, it may reach *flash point*, when small flames of fire begin in the oil. Subsequently, it reaches the *fire point* where a fire is sustained in the oil. Oils such as cottonseed or peanut oil have a high smoke point of 444 or 446°F (229 or 230°C), respectively. Other oils with a lower smoking point may not perform satisfactorily when exposed, for example, to the high heat of a wok.

CULINARY ALERT! Lard, butter, margarine, and animal fats have a low smoke point and less tolerance of heat compared to hydrogenated fat and oils.

Changes during Frying

Frying exposes the food product to high temperatures, removes internal water, and allows a level of oil absorption. The duration of frying, composition of the food, surface treatment, and other factors determine levels of oil uptake.

The subsequent thermal decomposition of oil occurs in fat as air, water, and prolonged high temperature leads to fat oxidation and hydrolysis. Oil may become an unwanted orange or brown color or it may become more viscous and foam. The smoke point decreases as oil is repeatedly used for frying, and the quality is reduced.

Many factors are reported to affect oil uptake during frying (8), and a better understanding of how oil is absorbed during frying can lead to improved food quality of fried foods. For example, porosity requires more study in order to determine its effect on oil uptake. Some of these factors are addressed in Table 12.3.

LOW-FAT AND NO-FAT FOODS

Consumer interest in eating reduced-fat or fat-free foods has increased, as is evidenced by the trend for more healthy foods. Yet, the per capita consumption of fats and oils has *not* decreased to meet the Surgeon General's recommendation

TABLE 12.3 Selected Factors That Affect Oil Uptake during Deep-Fat Frying

Frying temperature, duration, and product shape—Increases in temperature decreases oil uptake due to short frying duration.
Pressure frying decreases duration and oil uptake.
A high surface-to-mass ratio or surface roughness increases oil absorption.
Composition—The addition of soy protein, egg protein, or powdered cellulose decreases oil uptake. High sugar, soft flour, or developed gluten increase oil uptake.
Prefrying treatments—Blanching, prewashing with oil containing emulsifiers, freezing, and steam pretreatment have been shown to decrease oil uptake.
Surface treatment—Hydrocolloids (see Fat Replacements) and amylose coatings may function as barriers to fat uptake.

(<30% of a day's calories from fat) in the Report on Nutrition and Health. This may be due in part to the fact that the function, flavor, and mouthfeel of fat has *not* been duplicated by any nonfat component in the diet.

Product developers of reduced-fat food "need to consider the sensory experience of full-fat products" (9). A report on overcoming flavor challenges in low-fat frozen desserts states that the removal of fat in ice cream products affects flavor and aroma, texture, and mouthfeel. In overcoming flavor challenges, the following points must be considered:

- "Removing any significant amount of fat (above 25%) from a product changes the flavor profile. As the concentration is further reduced, the flavor challenges are increased significantly. As more fat is removed, the differences become much more apparent and the challenges to the product developer increase" (9).
- "When fat is removed from a formulation, the only ingredients available to replace it are water, protein, carbohydrates, minerals, or air. Even if nothing new is added to the formula, these items increase automatically and proportionally. Each of these components interacts differently with flavor than fat does. A combination of these ingredients may mimic part of fat's function, but they cannot totally replace fat's functionality" (10).
- The USDA reports one attempt at meeting flavor challenges. Utilizing a starch: lipid ratio varying from 10:1 to 2:1, oil droplets are suspended in cooked starch dispersions and then added as an ingredient to embellish flavor, texture, and mouthfeel (USDA).

FAT REPLACEMENTS

Fat replacements in a formulation may be protein, carbohydrates, or fat-based. Of course, the noncaloric water and air may be added if it works. Replacements are "useful when they help with calorie control and when their use encourages the consumption of foods delivering important nutrients" (11). In the following text, a discussion, examples, and a label designation are discussed for each group of derived fat replacers.

The use of a particular fat replacement may be determined by answering the question: What properties of fat are fat replacers attempting to simulate?

- "Organoleptically, fatty or oily mouthfeel can be described as a combination of several basic parameters that together form the recognizable edible sensation of fattiness or oiliness. These parameters are viscosity (thickness, body, fullness), lubricity (creaminess, smoothness), absorption/adsorption (physiological effect on tastebuds), and others (not yet defined but may include such factors as cohesiveness, adhesiveness, waxiness, mouthcoating, etc.)" (10).
- "Ingredients which provide these organoleptic stimuli can and do mimic fatty mouthfeel and perception and can be used to replace fat in many food products" (10).
- Today, there are many materials designed to replace fat; they are derived from several different categories of substances. Some replacers that attempt to simulate fat include protein-, carbohydrate-, and fat-derived fat replacements described below.

Using "the systems approach" in problem-solving, the Calorie Control Council reports that "... a variety of synergistic components are used to achieve the functional and sensory characteristics of the full-fat product. Combinations of ingredients are used to compensate for specific functions of the fat being replaced. These combinations may include proteins, starches, dextrins, maltodextrins, fiber, emulsifiers and flavoring agnts. Some fat replacers are now available that are themselves a combination or blend of ingredients (for example, one ingredients currently in use is a combination of whey, emulsifiers, modified food starch, fiber and gum)" (12).

The American Dietetic Association (ADA) states " Fat replacements provide an opportunity for individuals to reduce intake of high-fat foods and enjoy reduced-fat formulations of familiar foods while preserving basic food selction patterns." It is the position of the ADA that "the majority of fat replacers, when used in moderation by adults, can be safe and useful adjuncts to lowering the fat content of foods and may play a role in decreasing total dietary energy and fat intake. Moderate use of low-calorie, reduced-fat foods, combined with low total energy intake, could potentially promote dietary intake consistent with the objectives of *Healthy People 2010* and the 2005 *Dietary Guidelines for Americans*" (11).

Reported by the Institute of Food Technologists, "The final message to health-conscious consumers may be that there is no "magic bullet" to achieving dietary goals. A prudent approach, however, is combining proper nutrition, dietary variety, with a healthy lifestyle, regular exercise, and a reduction of total dietary fat aided by choosing foods formulated with fat replacers" (14). In the following text, a discussion, examples, and a label designation are discussed for each group of derived fat replacers.

Carbohydrate-Derived Fat Replacements

Fat replacements may be derived from carbohydrates with 0–4 kcal/g instead of 9 kcal/g. *Starches* work well as fat replacements in high-moisture systems to absorb water and form gels that mimic fat. They have been utilized in the bakery industry for many years. An example is a pregelatinized dull waxy cornstarch that is used to reduce fat in bakery products (13).

Fruit purees or dried puree powder also is used to replace fats, as are *cellulose, gums, fiber, dextrins, maltodextrins, modified food starch, modified dietary fibers and polydextros*. Starch hydrolysis derivatives known as ***maltodextrins*** (classified as hydrocolloids) are bland in flavor and have a smooth mouthfeel. They are fat-replacing ingredients of commercial cakes and also assist in maintaining product moisture. Gelling, thickening, and stabilizing are desirable functional properties.

The plant root, tapioca, and the tuber, potato, as well as the cereal starches corn and rice also are used as fat replacers. An oat-based fat replacement is made by partial hydrolysis of oat starch using a food-grade enzyme, and barley is being investigated for use as a possible fat substitute.

Glicksman (10) reports that there are currently eight or more categories of fat replacers that are basically hydrocolloid materials or contain hydrocolloids as an important part of their ingredient composition. ***Hydrocolloids*** are long-chain polymers, principally carbohydrate, that thicken or gel in aqueous systems, creating the creamy viscosity that mimics fat. Some are listed below. They include the starch derivatives, hemicelluloses, β-glucans, soluble bulking agents, microparticulates, composite materials [ie, carboxymethyl cellulose (CMC) and microcrystalline cellulose or xanthan gum and whey], and functional blends (gums, modified starches, nonfat milk solids, and vegetable protein).

Polydextrose (Chapter 17) may be used as a 1 kcal/g substitute for either fat or sucrose. Polydextrose is a bulking agent created by the random polymerization of glucose, sorbitol, and citric acid, 89:10:1. It may be used in a variety of products such as baked goods, chewing gum, salad dressings, gelatins, puddings, or frozen desserts.

Several dried-fruit-based substances are available for replacement of fat in recipes. Raisin, plum, and other fruit mixtures are available for consumer use at this time. Applesauce also is used to partially replace fat in formulations. Many additional fat replacers is being explored, including the use of encapsulated technologies (USDA).

Examples of Carbohydrate-Derived FDA Approved *or* Currently Researched Fat Replacers

- Cellulose [Avicel® (FMC Corp.), Methocel™, Solka-Floc®] various forms of microcrystalline cellulose from purified wood pulp (0 kcal/g) may replace some or all of the fat in frozen desserts and salad dressings.
- Dextins [Amylum, N-Oil® (National Starch and Chemical Corp.)]: may include tapioca maltodextrin (4 kcal/g) for cold food applications.

- Fiber (Opta™, Oat fiber, Ultracel™, Z-Trim): fiber for structure, volume, moisture holding capacity, stability in reduced fat products.
- Gums (KELCOGEL®, KELTROL®, Slendid™): hydrocolloids such as gums (guar, arabic, locust bean, xanthan), carrageenan, or pectin. Negligible calories.
- Inulin (Raftiline®, Fruitafit®, Fibruline®): fat and sugar replacer (1–1.2 kcal/g) in many cold foods and as a commercial fiber supplement.
- Maltodextrins (CrystaLean®, MALTRIN®, Paselli® D-LITE, Paselli® EXCEL, Paselli SA2®, STAR-DRI®): sources such as corn, potato tapioca, or wheat starch dextrin (4 kcal/g), used in cold food applications and confections. Fat replacer, texture modifier or bulking agent.
- Nu-Trim: β-glucan fat replacer hydrolyzed from oat or barley (the fiber also reduces CVD risk factors).
- Oatrim (Beta-Trim™): β-glucan amylodextrin hydrolyzed from oat fiber (1 kcal/g) cholesterol lowering benefit; in cold food applications and baked products.
- Polydextrose (Litesse®, Sta-Lite® Pfizer Inc.): water-soluble starch polymer made from dextrose, sorbitol, and citric acid (1 kcal/g), a fat replacer and bulking agent, in diverse foods.
- Polyols: Used as *sugar* replacers to provide the bulk of sugars; however, less calories (1.6–3.0 kcal/g). Also replaces the bulk of fats in reduced or fat-free products.
- Starch and modified food starch [Amalean® I and II, Fairnex™, Instant Stellar™ (corn) PURE-GEL®, STA-SLIM™ (1-4 kcal/g)]: diverse uses with protein, gums, modified food starches. Corn, oat, potato, rice, tapioca, wheat starch dextrins.
- Z-Trim (0 kcal/g) made from insoluble fiber from corn, oat, pea, and rice hulls, soybean and wheat bran. May replace part of flour.

Carbohydrate-based fat replacers on food labels: *Carrageenan, cellulose, gelatin, gellen gum, gels, guar gum, maltodextrins, polydextrose, starches, xanthum gum, modified dietary fibers.*

Fat-Derived Fat Replacements

Fat-derived fat replacements, such as Olestra, offer 0 cal/g. Other replacements offer less than 9 kcal/g of fat. The majority are *emulsifiers, emulsions with little fat, or analogs*: triglycerides or similar, with a changed configuration. It is reported by the International Food Information Council (IFIC) that "Some fat-based ingredients, such as Caprenin and Salatrim, are actually fats tailored to contribute fewer calories and less available fat to foods. Others such as olestra, are structurally modified to provide no calories or fat" (15)

Olestra, marketed under the brand name Olean®, differs from fats and oils in its chemical composition and properties. Olestra is a sucrose polyester (SPE), predominantly sucrose octaester, which is synthesized by reacting six to eight fatty acids with the eight free hydroxyl groups of sucrose (recall that fats are a glycerol backbone with three fatty acids attached). Each fatty acids may be 12–20 or more carbons in length and may be either saturated or unsaturated. Fatty acids may be derived from corn, coconut, palm, or soybean sources.

Olestra became the latest of several food ingredients approved without GRAS status [others are TBHQ (1972), aspartame (1981), polydextrose (1981), and acesulfame K (1988) (Chapter 17)]. Its chemical makeup and configuration make Olestra indigestible and it is not absorbed. Its numerous fatty acids are attached to the sucrose in a manner that cannot be easily penetrated by digestive enzymes in the length of time it is in the digestive tract. As a result, Olestra provides *no* calories.

Unlike *protein-derived* fat replacements, which by their nature *cannot* be exposed to high heat, Olestra is used for frying applications. It was first patented in 1971 and sought FDA approval as a cholesterol-lowering drug. Approval was denied, because such a use was not shown.

A subsequent petition in 1987 requested use of Olestra as a direct food additive. It was to be used as a fat replacement for (1) up to 35% of the fat in home-use cooking oils and shortenings, and (2) up to 75% of the fat in commercial deep-fat frying of snack foods. The petition was amended in 1990 and approved in 1996 to allow the Proctor and Gamble Olean® to be used as a 100% replacement for fats in savory snacks (salty, piquant, but not sweet, such as potato chips, cheese puffs, and crackers), including the frying oil and any fat sources in the dough (conditioners, flavors, etc.). All other uses of Olestra require separate petitions.

The FDA conclusions regarding the major chemical changes in frying and baking applications of Olestra are that changes are similar to triglycerides. The fatty acid chains oxidize in both cases. In baking, there is slower degrading of the fatty acids, but the same by-products are produced. Olestra has baking and frying applications and may be used in dairy-based or oil-based foods.

A special label statement is required for all Olean®-containing products. Labels must state "This product contains Olestra. Olestra may cause abdominal cramping and loose stools. Olestra inhibits the absorption of some vitamins and other nutrients. Vitamins A, D, E, and K have been added." In three small test markets, the major user of Olean® has not observed nor has there been evidence of severe abdominal cramps and loose stools resulting from the consumption of products containing Olean® (Frito-Lay).

Health concerns regarding the use of Olestra have been addressed in part by over 150 Procter and Gamble studies. Some concerns are:

- Olestra is an additive with very high use in foods compared to other additives
- Olestra may cause a loss of fat-soluble vitamins from the body
- it may leak and not be held by the final sphincter of the body in elimination: the anal sphincter

- it may negatively impact the environment and water quality through wastewater treatment

However, in answer to these concerns

- very few products contain Olestra, and it is not carcinogenic
- vitamins A, D, E, and K are added to Olestra-containing foods by manufaacturers
- a reformulation has created longer-chain fatty acids that do not leak from the digestive tract
- adverse environmental effects to the environment are not expected (16)

Caprenin® (Procter and Gamble) is another fat replacement that contains 5 cal/g. It contains a glycerol backbone with three fatty acids. Two of the fatty acids are medium chain—caprylic and capric—which are metabolized similarly to carbohydrates and the other chain consists of a long fatty acid—behenic acid—that is incompletely absorbed. These fatty acids are selected on the basis of specific, desired properties.

Nabisco Foods has developed a proprietary family of low calorie **salatrim** fats–named for **s**hort **a**nd **l**ong **a**cyl**tri**glyceride **m**olecule. SALATRIM is a patented ingredient of conventional glycerol backbones to which long-chain fatty acids and short-chain fatty acids are added. The long-chain stearic acid is combined with the short-chain acetic, propionic, and butyric acids on a glycerol molecule (17).

Nabisco states that SALATRIM is different from other fat replacers because it is made from real fat, whereas other fat substitutes are made from protein and carbohydrates, which “don’t give you the flavor and taste you need for baking” (18, 19). SALATRIM received GRAS status by the FDA in 1994. It was approved for use in baked products, chocolates and confections, dairy products, and snacks, but it cannot be used successfully in frying applications.

A nutritional advantage of using these fat replacers is that they contain 5 kcal/g, instead of the normal fat amount of 9 kcal/g. This calorie reduction may be due to hydrolysis of short-chain fatty acids that are rapidly hydrolyzed to carbon dioxide and longchain fatty acids that are incompletely absorbed.

Examples of Fat-Derived FDA Approved *or* Currently Researched Fat Replacers

- Caprenin® (Proctor & Gamble): a triglyceride with capric, caprylic, and behenic fatty acids (5 kcal/g) may be withdrawn from the market as it may increase serum cholesterol.
- SALATRIM (Benefat™): **s**hort **a**nd **l**ong **a**cyl **tri**glyceride **m**olecule containing fat and acids from fruit and vinegar (5 kcal/g).
- Emulsifiers (Dur-Lo®, EC™-25): emulsifiers with the same caloric value of 9 kcal/gm; however, less is used, so less fat and calories get used. May be sucrose fatty acid esters.

- Lipid analogs: Esterified propoxylated glycerol (EPG) analogs, Olestra, Olean® (Procter & Gamble Co.), sucrose polyester (0 kcal/g), sorbestrin (1.5 kcal/g), used in fying and baking applications. [Calorie Control Council (www.caloriecontrol.org/fatreprint.html)].
  A recent addition is Enova Oil®. It contains a diacylglycerol component that is metabolized differently than a trigylceride. It is more likely to be burned as energy than stored as fat.

Fat-based fat replacers on food labels: Caprenin, salatrim (Benefat®), mono- and diglycerides, olestra (Olean®). (The ingredient may be used for reasons other than fat replacement).

Protein-Derived Fat Replacements

Proteins may be used in place of fat. They contribute 1–4 kcal/g, instead of 9. An easily recognized type is gelatin; however, there are others. The International Food Council states that "Some protein-based ingredients, such as Simplesse®, are made through a process that gives fat-like textural properties to protein. Other proteins are heated and blended at high speed to produce tiny protein particles that feel creamy to the tongue. … protein-based fat reducers cannot be used as substitutes for oils and other fats in frying" (15).

Simplesse® is a natural fat substitute developed by the NutraSweet Company and approved by the Food and Drug Administration (FDA) in 1990. It is a *microparticulated protein (MPP)*. Simplesse® uses a patented process that heats and intensely blends naturally occurring food proteins such as *egg white and milk* proteins, along with water, pectin, and citric acid. The protein remains chemically unchanged but aggregates under controlled conditions that allow formation of small aggregates or microparticles.

The *blending* process produces small, round uniformly shaped protein particles—about 50 billion per teaspoon—that create the creamy mouthfeel of full fat. The microparticulated particle size is near the lower range of *MPPs* that naturally occur in milk, egg white, grains, and legumes. For example, casein (milk protein) micelles range in size from 0.1 to 3.0 mm in diameter and are perceived as creamy to the tongue. In comparison, a larger particle size, 10–30 mm in diameter, is found in powdered (confectionery) sugar, which is perceived as more powdery and gritty.

Initially, Simplesse® was an ingredient approved by the FDA for use in dairy-based frozen desserts. Today, it has many more food applications in products such as butter spreads, cheese (creamed, natural, processed, baked cheesecakes), creamers, dips, ice cream, and sour cream. It also is successfully incorporated into oil-based products such as margarine spreads, mayonnaise, and salad dressings.

Simplesse® has applications in some aspects of cooking and baking. It may be used in *some* heat processes such as canning or pasteurization, but due to its protein composition, it is subject to denaturation and *cannot* be used in *frying* applications. NutraSweet® also has created a series of three bakery blends using

Simplesse® for specific fat-free, lowfat, or reduced-fat bakery applications. The blends create a fat reduction of 83–93% in muffins, pound cakes, and brownies and are used at levels of 1.0–3.0%. Powdered bakery blends are used for muffins, sweet dough products, and frostings. They are Kosher approved and with proper storage they have a shelf life of 9 months (20).

Due to its milk and egg protein composition, individuals *allergic* to milk or eggs *cannot* eat this fat substitute. It contains 1.2 cal/g (*not* a zero-calorie food), approximately onethird the calories of protein, and significantly lowers fat intake. Simplesse® is a generally recognized as safe (GRAS) substance.

Whey protein concentrates (WPCs), *isolates* (WPIs), and isolated soy protein (legumes) are proteins that can be used to provide some of the functional properties of fat without the same number of fat calories. Dairy-Lo® is an example of a WPC and uses include dairy products, baked goods, frostings, mayonnaise-type products, and salad dressings.

Soy may be used for emulsification or gelling and is approved for addition of up to 2% in cooked sausage and cured pork. It may be used at higher levels in ground meat and poultry.

Examples of Protein-Derived FDA Approved *or* Currently Researched Fat Replacers

- Microparticulated protein (Simplesse® Nutrasweet Co.) MPP of egg and milk or whey protein. Egg white and milk protein, water, pectin, and citric acid) (1–2 kcal/g), useful in cold food applications.
- Modified whey protein concentrate (Dairy-Lo®).
- Egg white and milk similar to MPP; however, a different process (K-Blazer®, ULTRA-BAKE ™, ULTRA-FREEZE™, Lita®). (Calorie Control Council)

Protein-based Fat Replacers on Food Labels: Whey protein concentrate, microparticulated egg white, and milk protein (Simplesse®).

Beyond the scope of this discussion is more information that defines fat replacers and extenders. For example, fat substitutes, fat analogs, fat mimic, fat extender, and fat barriers are terms better defined elsewhere in the literature.

NUTRITIVE VALUE OF FATS AND OILS

Food guides such as the food pyramid suggest that fat be used sparingly. Most health authorities in the United States agree with this recommendation. Fats are needed for numerous functions in the human body, and two polyunsaturated fatty acids are essential—linoleic and linolenic acid—which are required for human growth. In addition to the many roles fat plays in functionality of foods, fats are a very concentrated energy source—providing 9 cal/g. This is 2$\frac{1}{4}$ times as many calories per gram as either carbohydrates or protein. Labeling studies have indicated that fat and calories are the two most frequently read items on food labels (21).

Whereas the *food technologist* looks at industrial "processing methods to enhance the quality of existing fats and oils" such as hydrogenation and interesterification, *plant breeders* work "to produce new vegetable oils with altered fatty acid composition" (21). In combination, the more methods and *biotechnology* can be used to facilitate breeding and create more healthful fats. Breeders look at new crops containing selected fatty acids from which fats can be designed (22). Biotechnology, such as genetic engineering and enzyme techniques, has potential in enhancing quality of vegetable oils because of the time reduction (possibly 50% shorter) and targeting gene manipulation (22).

The health-conscious consumer may make choices of reducing certain foods that are major contributors of less desirable fatty acids, and as well substitute foods, possibly *increasing* fats that are major contributors of the fatty acids that are desired (23). Consumers' switch in use of cooking oils, the health aspects of a variety of foods containing fats and oils, familiarity with fat and health terminology, and eating trends are reported elsewhere (21, 25, 26).

The food industry may have a major impact in reducing heart disease, as they have *changed* formulations containing *lard and tallow* to *vegetable oil* such as corn and soybean oil, which contain essential fatty acids. They also have replaced fat in formulations. Both of these steps have major impact on reducing heart disease (24).

In 1998, the first high-oleic, low-polyunsaturated fatty acid line of soybean oil became commercially available. A nutritional advantage is that it contains approximately 83% monounsaturates, 5% polyunsaturates, and 11% saturated fatty acids. The use of this oil may decrease the risks of heart disease. With its inclusion in food products, a reduction of the *trans* fatty acid level from the partially hydrogenated fat is also possible.

One can see that an interest in reducing *trans* fatty acids continues. Although previously mentioned, a further statement by the FDA on *trans* fatty acids is included in this section on nutritive value.

Food Labeling: Trans Fatty Acids in Nutrition Labeling, Nutrient Content Claims, and Health Claims

> "SUMMARY: The Food and Drug Administration (FDA) is amending its regulations on nutrition labeling to require that trans fatty acids be declared in the nutrition label of conventional foods and dietary supplements on a separate line immediately under the line for the declaration of saturated fatty acids. This action responds, in part, to a citizen petition from the Center for Science in the Public Interest (CSPI). This rule is intended to provide information to assist consumers in maintaining healthy dietary practices ..." (Department of Health and Human Services, FDA (21 CFR Part 101)

Another item of interest in a fats and oils discussion is cholesterol. Similar to the role of cholesterol in animal cell membranes, *phytosterols* perform the same role in *plants*. The structures are alike, differing only in the side chain (Figure 12.4). *Plant sterols* are commercially available in margarines and salad dressings, and although there are several theories suggested and the precise mechanism is unknown, phytonutrients have been shown for many decades to significantly reduce low-density lipoprotein (LDL) or “bad” cholesterol. They inhibit the uptake of endogenous and dietary cholesterol.

Due to the knowledge of their health benefits, more phytosterols are expected to be included in margarines and other foods as a cholesterol-lowering functional food ingredient (Chapter 20). The cost factor continues to be a challenge, as is the marketing of any “healthy food” that incorporates new ingredients.

CONCLUSION

Fats and oils add or modify flavor, aerate batters and doughs, contribute flakiness and tenderness, emulsify, transfer heat, and provide satiety. They are composed of a glycerol molecule with one, two, or three fatty acids attached creating mono-, di-, or triglycerides, respectively. Minor components of fats and oils include phospholipids, sterols, tocopherols, and pigments. Fatty acid chains of even number may exist as geometric or positional isomers. Nomenclature may be according to a common name, systemic or Geneva name, or omega system.

Fats and oils exist in several crystalline forms and have different melting points. Solid fats have higher melting points than oils. Fats and oils may be processed by being deodorized or rendered. They are modified by hydrogenation, inter-esterification, acetylation, or winterization.

The deterioration of fats and oils occurs as they absorb odors or become rancid. Hydrolytic rancidity releases free fatty acids and oxidative rancidity produces shorter, off-odor free radicals catalyzed by heat, light, metals, or enzymes. Prevention of oxidation by avoiding catalysts in the environment or by the addition of sequestering agents or antioxidants may be useful in extending shelf life.

Monoglycerides and diglycerides have uses as emulsifiers, permitting fats and liquids to mix. Fats and oils are useful as shorteners; they tenderize and produce flakes in baked products. They also may be used in the preparation of salad dressings and for frying applications. Foods may contain reduced-fat, low-fat, or no-fat formulations using a variety of fat replacers derived from carbohydrates, proteins, or fats.

Plant breeders are researching the development of healthier fats. A variety of vegetable oils continue to be available to food processors and to a lesser extent to the consumer. Stability without increased saturation is the goal of processors. Advanced hybridization of vegetable sources of oil may reduce saturated fatty acids, and thus improve nutritional value. Fats and oils should be used sparingly in the daily diet.

GLOSSARY

Acetin fat: A triglyceride with one or two fatty acids on a triglyceride replaced by acetic acid; this decreases the melting point.

Acetoglyceride: Acetin fat.

Antioxidant: Prevents, delays, or minimizes the oxidation of unsaturated bonds by donating a H atom to the double bond in a fatty acid.

Autoxidation: Progressive oxidative rancidity in an unsaturated fatty acid promoted by heat, light, the metals iron and copper, and lipoxygenases.

BHA: Butylated hydroxyanisole; an antioxidant.

BHT: Butylated hydroxytoluene; an antioxidant.

Cis configuration: A double-bond formation when H atoms attach to the C atoms of the double bond on the same side of the double bond.

Continuous phase: The phase or medium in which the dispersed phase is suspended in an emulsion.

Deodorized oils: Oils that have undergone the process of removing odors by heat and vacuum or by adsorption onto charcoal.

Dispersed phase: A phase that is disrupted or finely divided in the continuous phase of an emulsion.

Emulsifier: Bipolar substance with a hydrophilic and hydrophobic end, which reduces surface tension and allows the ordinarily immiscible phases of a mixture to combine.

Fat replacement: A substance used to replace fat in a formulation; these may be protein, carbohydrate, or fat-based.

Flakiness: Thin, flat layers formed in some dough products desirable in biscuits or pie crusts.

Hydrocolloid: Long-chain polymers; colloidal material that binds and holds water.

Hydrogenation: Process of adding H to unsaturated fatty acids to reduce the number of double bonds; an oil becomes more solid and more stable in storage.

Hydrolytic rancidity: Reaction of fats with water to liberate free fatty acids.

Hydrophilic: Water-loving substance attracted to water.

Hydrophobic: Water-fearing substance attracted to fat.

Interesterification: Rearrangement as fatty acids migrate and recombine with glycerol in a more random manner.

Interfacial tension: See surface tension.

Isomer: Fatty acids have the same number of carbons, hydrogens, and oxygens but form different arrangements that create different chemical and physical properties.

Lecithin: Phospholipid of two fatty acids esterified to glycerol and a third group of phosphoric acid and choline as the N group, useful as an emulsifier.

Maltodextrin: Hydrocolloid; starch derivative of tapioca, potato, corn, rice, oats, or barley that may be used to replace fat in a formulation.

Oxidative rancidity: Fat is oxidized and decomposes into off-odor compounds with shorter-chain fatty acids, aldehydes, or ketones.

Plastic fat: Able to be molded and hold shape; contains both liquid and solid triglycerides in various ratios.

Phospholipid: A lipid containing two fatty acids and a phosphoric acid group esterified to glycerol.

Polymorphism: Fats existing in different crystalline forms: α, β' intermediate, β.

Rearrangement: Interesterification of fatty acids on glycerol, ie, modified lard.

Rendered: Fat freed from connective tissue and reduced, converted, or melted down by heating; for example, lard is rendered hog fat.

Sequestering agent: Binds metals, thus preventing them from catalyzing autoxidation; for example, EDTA, citric acid.

Smoke point: The temperature at which fat may be heated before continuous puffs of blue smoke come from the surface of the fat.

Sterols: A lipid containing a steroid nucleus with an 8–10 C side chain and an alcohol group; cholesterol is the most well known.

Surface tension: (Interfacial tension) force that tends to pull molecules at the surface into the bulk of a liquid and prevent a liquid from spreading. Reduction of surface tension enables a liquid to spread more easily.

Tenderization: Easily crushed or chewed, soft, fragile, baked dough.

TBHQ: Tertiary butylated hydroquinone; an antioxidant.

Tocopherols: Minor component of most vegetable fats; antioxidant; source of vitamin E.

Trans configuration: A double-bond formation in fatty acids where the H atoms attach to the C atoms of the double bond on opposite sides of the double bond.

Winterized: Salad oil that is pretreated prior to holding to control undesirable cloudiness from large, high-melting-point triglyceride crystals.

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CHAPTER 13

Food Emulsions and Foams

INTRODUCTION

Many convenience foods, such as frozen desserts, meat products, and margarine, and some natural foods, such as milk and butter, are emulsions. That is, they contain either water dispersed in oil or oil dispersed in water. These liquids do not normally mix, and so when present together they exist as two separate layers. However, when an emulsion is formed, the liquids are mixed in such a way that a single layer is formed with droplets of one liquid dispersed within the other. Food emulsions need to be stable; if they are not, the oil and water will separate out. Stability is usually achieved by adding a suitable emulsifier. In some cases, a stabilizing agent is also required.

Food foams, such as beaten egg white, are similar to emulsions except that instead of containing two liquids, they contain a gas (usually air or carbon dioxide) dispersed within a liquid. The factors affecting stability of emulsions also apply to foams. Some foods, such as ice cream and whipped cream, are highly complex, being both an emulsion and a foam.

Understanding of food emulsions and foams is complex but is important if progress is to be made in maintaining and improving the stability, and hence the quality of these types of foods. This chapter will discuss the principles of formation and stability of emulsions and foams and the characteristics of the ingredients necessary to stabilize them.

EMULSIONS

Definition

An ***emulsion*** is a ***colloidal system*** containing droplets of one liquid dispersed in another, the two liquids being immiscible. The droplets are termed the ***dispersed phase***, and the liquid that contains them is termed the ***continuous phase***. In food emulsions, the two liquids are oil and water. If water is the continuous phase, the emulsion is said to be an ***oil-in-water*** or ***o/w emulsion***, whereas if oil is the continuous phase the emulsion is termed a ***water-in-oil*** or ***w/o emulsion***. Oil-in-water emulsions are more common and include salad dressings, mayonnaise, cake batter, and frozen desserts. Butter, margarine, and some icings are examples of water-in-oil emulsions.

An emulsion also must contain an ***emulsifier***, which coats the emulsion droplets and prevents them from ***coalescing*** or recombining with each other. Emulsions are colloidal systems because of the size and surface area of the droplets (in general, around 1 μm, although droplet size varies considerably and some droplets may be a lot larger than this). Emulsions are similar to colloidal dispersions or sols, except that the dispersed phase is liquid and not solid. Colloidal dispersions are mentioned in Chapter 2.

Surface Tension

To form an emulsion, two liquids that do not normally mix must be forced to do so. To understand how this is achieved, we must first consider the forces between the molecules of a liquid. Imagine a beaker of water placed on a desk (Figure 13.1).

The water molecules are attracted to one another other by hydrogen bonds as described in Chapter 2. A molecule in the center of the beaker has forces acting on it in all directions, because water molecules surround it. The net force on this molecule due to attraction by other water molecules is zero, because these forces are acting in all directions. However, this is not the case for a water molecule on

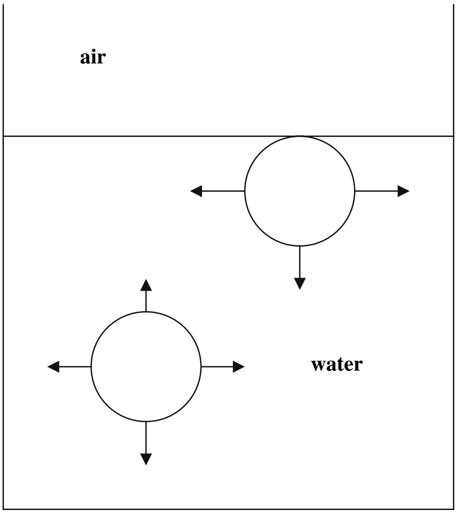

FIGURE 13.1 Diagram of the forces acting on water molecules in the bulk and at the surface of the liquid.

the surface. Since there are no water molecules above it, there is a net downward pull on the molecule. This results in the molecule being pulled in toward the bulk of the liquid. This can be seen when one fills a narrow tube such as a pipette or a burette with water. The surface of the liquid curves downward at the center and the curve is called the **meniscus**. The greater the attractive forces between the liquid molecules, the greater the depth of the meniscus. Water molecules have strong attractive forces among them, and so it is relatively difficult to penetrate the surface or to get the water to spread. Try placing a needle gently on the surface of clean or distilled water. It will float, because the attractive forces between the water molecules keep it on the surface. (To make it sink, see below.)

If there are strong attractive forces among the molecules of a liquid, the force required to pull the molecules apart to expand the surface or to spread the liquid will be high. This force is known as ***surface tension***. A liquid such as water, with strong attractive forces among the molecules, has a high surface tension. This makes it difficult to spread. You can see this if you put water on a clean surface. It will tend to form droplets rather than spreading evenly as a thin film across the surface. (A droplet has minimal surface area and maximal internal volume, and so is the most energetically favorable shape for liquids with a high surface tension, where the molecules are being pulled into the interior.)

The term "surface tension" normally is used when a *gas* (usually air) surrounds the *liquid* surface. When the surface is between two *liquids*, such as water and oil, the term ***interfacial tension*** is used.

A high surface or interfacial tension makes it difficult to mix the liquid either with another liquid or with a gas. This is a drawback when making an emulsion or foam and needs to be overcome. So how can surface tension be reduced?

Surface-Active Molecules

To reduce the surface or interfacial tension, something must be done to decrease the attractive forces between the liquid molecules, so that it is easier to spread them. This can be achieved by adding a ***surface-active*** molecule, or a ***surfactant***. As their name suggests, surface-active molecules are active at the *surface* of a liquid, rather than at the bulk of it. Surfactant molecules prefer to exist at the surface of a liquid rather than at the bulk because of their structure. In all cases, a section of the molecule is water-loving or ***hydrophilic***, because it is polar or charged, and a section is water-hating or ***hydrophobic***, because it is apolar. In other words, the molecules are ***amphiphilic***.

The apolar section has little or no affinity for water and so it is energetically favorable for this section to be as far away from the water as possible. However, the polar section is attracted to the water and has little or no affinity for the oil. Therefore, the molecule orients at the surface with the polar section in the water but the apolar section either in the air or in the oil (see Figure 13.2).

Because the molecule ***adsorbs*** at the surface, it reduces the attractive forces of the water molecules for themselves and makes it easier to expand or spread the surface. In other words, it reduces the surface or interfacial tension.

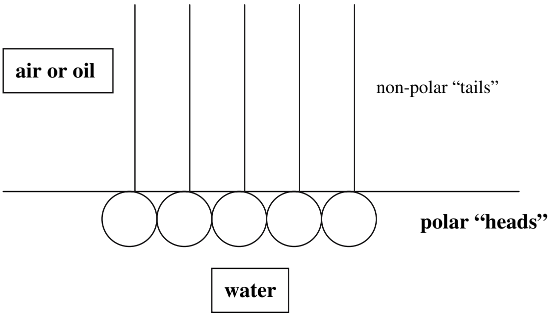

FIGURE 13.2 Orientation of amphiphilic molecules at an interface.

Detergent is an example of a surfactant. When detergent is added to water, it enables the water molecules to spread much more easily, so that they wet a surface more readily. After adding detergent, water will flow over a surface, forming a thin sheet, instead of tending to gather into droplets. Going back to the example of the needle floating on water (see above), if a small drop of detergent is added, the needle will sink. The surface tension is reduced, allowing the water molecules to spread more easily, and so the needle no longer stays on the surface.

Obviously, detergents are not used as food ingredients! (However, they are used when washing dishes, because they enable the water to spread across the surface and remove food particles more easily.) There are many food ingredients that are surfactants. Polar lipids such as lecithin, which has a polar "head" and an apolar "tail," are surfactants and may be used as food additives to increase the wettability and aid in mixing of products like hot chocolate mix.

Proteins are surface-active because they contain both hydrophilic and hydrophobic sections. The nature and extent of these sections depend on the specific amino acid sequence of each protein, and some proteins orient at the surface more readily than others do (proteins are discussed in Chapter 8).

Some spices, such as dry mustard and paprika, also are used as surface-active ingredients. These finely divided powders tend to gather at the surface rather than the bulk of the liquid.

Molecules that are either hydrophilic or hydrophobic do not orient at an interface, but remain in the bulk of the liquid. For example, sugars, which are hydrophilic, or salt, which dissociates into ions, will be located in the bulk water phase. These types of molecules are not surface-active and will not decrease the interfacial tension. In fact, they may increase it, depending on their ability to bind the water molecules, hence increasing molecular attraction.

Emulsion Formation

An emulsion is formed when oil, water, and an emulsifier are mixed together. Although there are different food emulsions, they *all* contain these three components. To form an emulsion, it is necessary to break up either the oil or the water phase into small droplets that remain dispersed throughout the other liquid. This requires energy and usually is carried out using a mixer or a homogenizer. As the oil and water are mixed, droplets are formed. (They may be oil or water, but are usually oil droplets.) An emulsifier is adsorbed at the surface of new droplets, decreasing the interfacial tension and allowing formation of more and smaller droplets. The lower the surface or interfacial tension of the oil and water, the more easily one liquid can be disrupted to form droplets and the more easily the other liquid will flow around the droplets. The liquid with the higher interfacial tension will tend to form droplets, and the other liquid will flow around the droplets to form the continuous phase. The emulsifier generally determines the liquid that would form the continuous phase. Emulsifiers that are more easily dispersed in water (and therefore are more hydrophilic overall) tend to reduce the interfacial tension of the water more than that of the oil, promoting formation of o/w emulsions. Emulsifiers that disperse more readily in the oil phase tend to form w/o emulsions. The emulsifier usually is dispersed in the preferred phase before the oil and water are mixed together.

PRINCIPLES OF FORMATION OF A STABLE OIL-IN-WATER EMULSION

- Emulsifier is dispersed in the aqueous phase.
- Oil is added and the interfacial tension of each liquid is reduced by the emulsifier.
- Energy is supplied by beating or homogenizing the mixture.
- The oil phase is broken up into droplets, surrounded by water.
- Emulsifier adsorbs at the freshly created oil droplet surfaces.
- Small droplets are formed, protected by an interfacial layer of emulsifer.
- The interfacial area of the oil becomes very large.
- The aqueous phase spreads to surround each oil droplet.
- The emulsion may become thick due to many small oil droplets surrounded by a thin continuous phase.
- If the interfacial film is strong, the emulsion will be stable.

An emulsifier does not simply reduce interfacial tension. It also must form a stable film that protects the emulsion droplets and prevents separation of the emulsion. The droplets are continually moving through the continuous phase, and so they constantly encounter or collide with each other. When two droplets collide, one of the three things happens, as shown in Figure 13.3:

1. The emulsifier film stretches or breaks and the droplets combine to form one larger droplet (or in other words, they coalesce). This ultimately leads to separation of the emulsion.

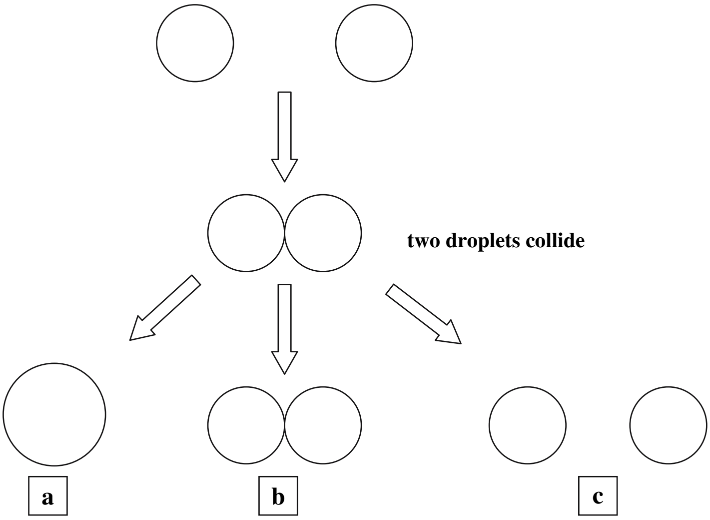

FIGURE 13.3 Diagram to illustrate what may happen after two droplets collide. a: coalescence b: aggregation c: droplets move apart again

2. The two emulsifier layers surrounding the droplets interact and an aggregate is formed. This occurs when a cream layer develops on top of fresh milk.
3. The droplets move apart again.

Which of these three events occurs depends on the nature of the emulsifier molecules and on their ability to completely coat all the emulsion droplets with a stable, cohesive, ***viscoelastic*** film. A viscoelastic film tends to flow to coat any temporarily bare sections of the surface and also is able to stretch instead of breaking when, for example, another droplet bumps into it. Therefore, it is less likely to break when droplet collisions occur. As the droplets are formed, their surface or interfacial area increases dramatically, and sufficient emulsifier must be present to completely coat all the droplet surfaces. Incompletely coated droplets will coalesce resulting in larger droplets and ultimately in separation of the emulsion.

Emulsifiers

Emulsifiers must be able to:

- Adsorb at the interface between two liquids such as oil and water.
- Reduce the interfacial tension of each liquid, enabling one liquid to spread more easily around the other.
- Form a stable, coherent, viscoelastic interfacial film.
- Prevent or delay coalescence of the emulsion droplets.

Reduction of the interfacial tension facilitates emulsion formation, because it reduces the amount of energy needed to break up one liquid into droplets and to spread the other liquid around them. Formation of a film that prevents coalescence promotes emulsion stability.

All emulsifiers are surfactants, because all emulsifiers adsorb at the surface and reduce interfacial tension. However, all surfactants do *not* make good emulsifiers, because not all surfactants are able to form a stable film at the interface and prevent coalescence. The stability of the film is important in determining the stability and shelf life of the emulsion. Some emulsifiers work better than others do in terms of forming a stable emulsion. In general, large macromolecules such as proteins form stronger surface films than smaller surfactant molecules such as lecithin, because of their greater ability to extend over the droplet surface. They also have a greater ability to interact with other groups within the same molecule or on different molecules and are able to form viscoelastic surface films. Small molecules are not usually able to form stable interfacial films by themselves and their role normally is that of a surfactant rather than an emulsifier, in that they lower interfacial or surface tension and promote spreading or wettability. Although they do not make good emulsifiers, they are often called emulsifiers. Many food scientists do not differentiate between surfactants and emulsifiers and so the words may be used interchangeably in some cases. However, in the world of a colloid scientist, there is a clear distinction between the two.

Characteristics of an emulsifier:

- Contains hydrophilic and hydrophobic sections (amphiphilic)

Functions of an emulsifier:

- Adsorbs at the oil / water interface
- Reduces interfacial tension

} facilitates emulsion formation

- Forms a stable interfacial film
- Prevents coalescence

} promotes emulsion stability

Natural Emulsifiers

The best emulsifiers are proteins, which uncoil or denature and adsorb at the interface and interact to form a stable interfacial film. Proteins tend to uncoil such that their hydrophobic sections are oriented in oil and their hydrophilic sections are oriented in water. Hence, a series of loops, trains, and tails may be envisioned at the interface, as shown in Figure 13.4.

The loops and tails are able to interact with each other, thus forming a stable film that resists rupture. The proteins of *egg yolk* tend to be the best emulsifiers, as exemplified by their use in mayonnaise. These proteins are lipoproteins and are

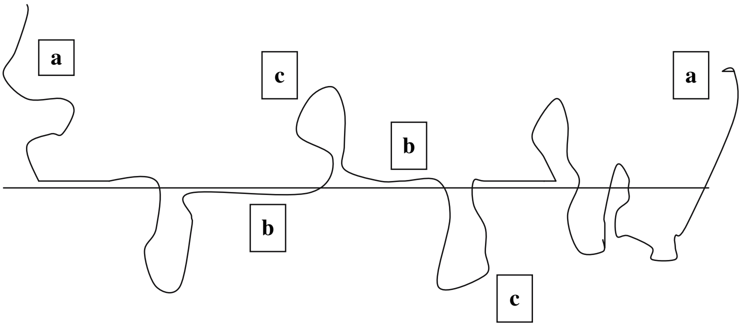

FIGURE 13.4 Schematic diagram of a protein adsorbed at an interface.
a: tails b: trains c: loops

associated with each other and with phospholipids such as lecithin in structures known as micelles. These micellar structures appear to be responsible for the excellent emulsifying properties of egg yolk proteins.

The *caseins* of milk are also excellent emulsifying agents. They are important emulsifiers in homogenized milk and in dairy desserts. In fresh (unhomogenized) milk, the caseins are associated with each other in structures known as casein micelles. Electron micrographs have shown that after homogenization, intact micelles are present at the fat globule surfaces, as well as individual protein molecules. It is thought that the micelles are responsible for the stability of homogenized milk, rather than the individual protein molecules.

Other food proteins used as emulsifiers include *meat* proteins and *soy* proteins. Lecithin is *often* considered to be an emulsifier. Lecithin is a surfactant and is useful for promoting wettability and aiding mixing of products such as hot drink mixes. However, it does not usually form strong interfacial films by itself and so would not be the emulsifier of choice unless other emulsifiers or stabilizers were added.

Synthetic Emulsifiers or Surfactants

Most synthetic emulsifiers would more correctly be termed *surfactants*, because they are relatively small molecules compared with proteins, and they are used mainly to aid in dispersion of fat rather than to stabilize emulsions. Surfactants such as *mono-* and *diglycerides* are added to shortening and to cake mixes to aid in dispersion of the shortening. Cakes are complex in that they contain fat droplets and air bubbles, and so are both emulsions and foams. (Foams are discussed later in this chapter.) The mono- and diglycerides enable the shortening to be dispersed into smaller particles, and this promotes incorporation of a large number of air cells, which increases cake volume and promotes a more even grain in baked products (Chapter 15).

Glycerol monostearate is an example of a monoglyceride that is commonly used in foods. Acids may be esterified with monoglycerides to give another group of surfactants, including sodium stearoyl-2-lactylate, which often is used in baked products. Two other groups of manufactured surfactants include the *SPANS*, which are fatty acid esters of sorbitan, and the *TWEENS*, which are fatty acid esters of polyoxyethylene sorbitan. Although all surfactants are amphiphilic, they have different degrees of hydrophobic (***lipophilic***) and hydrophilic character. This can be expressed as the ***hydrophilic/lipophilic balance,*** or ***HLB***. An HLB scale has been developed, which goes from 1 to 20. Surfactants with a low HLB (3–6) have more hydrophobic or lipophilic character. These would be used to form a w/o emulsion. Examples include glycerol monostearate and sorbitan monostearate (SPANS 60). Surfactants with a high HLB (8–18) have more hydrophilic character and form w/o emulsions. Examples would be polyoxyethylene sorbitan monostearate (TWEENS 60) or sodium stearoyl-2-lactylate. SPANS usually have a low HLB and form w/o emulsions, whereas TWEENS have a high HLB and form o/w emulsions. The HLB scale is useful to food scientists to help them in determining which emulsifier is most suited to their needs.

Examples of Emulsions

French dressing is an example of a ***temporary emulsion***, or in other words, an unstable emulsion that separates fairly soon after formation. The basic ingredients of French dressing are oil (the dispersed phase), vinegar (the continuous phase), dry mustard, and paprika. Other ingredients may be added for flavor. The "emulsifiers" used here are the mustard and paprika. Combining the ingredients and shaking them vigorously forms the emulsion. The mustard and paprika adsorb at the interface and reduce interfacial tension as the dressing is shaken, thus facilitating formation of an emulsion, but they do not interact at the interface to form a stable film. Hence, when shaking is stopped, the oil droplets are not protected, and so they soon coalesce and the oil and vinegar layers separate.

Mayonnaise is an example of a ***permanent emulsion***, since it is stable and does not separate under normal handling conditions. The main ingredients of mayonnaise are oil (the dispersed phase), vinegar (the continuous phase), and egg yolk. The egg yolk proteins, being excellent emulsifiers, protect the oil droplets against coalescence. Mayonnaise usually contains about 75% oil, which exists as stable droplets surrounded by a thin aqueous film. It is unusual in that it contains so much more dispersed phase than continuous phase. Generally, the continuous phase is present in greater quantity. Mayonnaise is made by slowly pouring small amounts of oil at a time into the vinegar and egg yolk mixture and continuing to beat to break up the oil into droplets and form the emulsion. As more oil is added, more droplets are formed, and the surface area increases dramatically. The continuous phase spreads out to surround the oil droplets and becomes a thin film. It is difficult for the droplets to move around, since they are packed tightly together and separated only by a thin film of aqueous phase; thus the mayonnaise becomes very thick and may even be stiff enough to cut. Some salad dressings may be similar to mayonnaise, except that they contain less oil and have a thinner consistency. Adding stabilizers such as gums or starches often enhances the stability of the emulsion.

Milk is an example of an emulsion that occurs in nature (Chapter 11). Milk contains about 3.5% fat in emulsified form. In fresh (unhomogenized) milk, the fat droplets are stabilized by a complex protein membrane known as the milk fat globule membrane. Fresh milk is a stable emulsion, but will cream fairly quickly if left to stand. The fat droplets vary in size from about 0.1 to 10 μm. There are many more small droplets than large ones, but because of their size the larger ones account for most of the fat. Because of the density difference between the milk fat and the aqueous phase, the fat droplets tend to rise though the milk. This is especially true for the larger droplets. Milk fat globules are unique in that as they rise, they tend to cluster together. This results in larger fat particles, which rise even faster. Hence, after a few hours, a cream layer can be seen at the top of the milk. This is not a true separation of oil and water, since the cream layer is still an emulsion and the interfacial film is still intact. The milk has separated into a concentrated emulsion and a dilute one. The cream can be removed and either used as cream or made into butter. Homogenizing the milk, which breaks up the fat globules into much smaller ones, prevents this creaming effect.

Factors Affecting Emulsion Stability

Obviously, the main factor affecting emulsion stability is the *emulsifier* itself. As has been discussed, emulsifiers that form stable interfacial films produce stable emulsions. There also must be sufficient emulsifier to completely coat the surface of all the droplets in order to ensure stability. *Droplet size* also is important because larger droplets are more likely to coalesce. Also, because of the density difference between oil and water, large oil droplets will tend to rise through the emulsion more quickly, creating a more concentrated emulsion closer to the surface, as is seen in milk. This may cause the emulsion to break.

Changing the *pH* by adding acid or changing the *ionic strength* by adding salts may reduce the stability of the interfacial film, especially if it is made of protein. Such changes may denature the protein, as explained in Chapter 8, and cause the emulsion to separate.

Another factor affecting emulsion stability is the *viscosity* of the emulsion. The thicker the emulsion, the lesser the movement of the molecules within the system and the longer it will take for the two phases to separate. Emulsions can be made thicker by adding ingredients such as gums, pectin, or gelatin. If gums are added to French dressing, a permanent emulsion may be formed without the need for egg yolk as the emulsifier. Gums often are added to emulsions as stabilizers. They are not emulsifiers themselves and they do not normally adsorb at an interface, because they are hydrophilic. However, they act by increasing the viscosity of the system, which slows movement, and hence reduces the number of collisions between droplets. This slows down and may prevent separation of emulsions.

Storage and *handling* affect emulsion stability. Although some emulsions are termed permanent, it should be noted that all emulsions are delicate systems that are inherently unstable, because they contain two immiscible liquids and the wrong handling conditions can cause emulsion breakage.

Temperature also affects emulsion stability. When emulsions are warmed, the oil droplets become more fluid and coalescence is more likely. On the other hand, cooling an emulsion to refrigeration temperatures may cause some solidification of the oil droplets, depending on the composition of the oil. This may enhance stability. Most emulsions do not survive freezing conditions. This is usually because the proteins at the interface become denatured or because the interfacial film is physically disrupted by the formation of ice crystals. *Gums* often are added to emulsions that are to be frozen to enhance stability.

Heat and *violent shaking* also are likely to disrupt emulsions. For example, cream is converted to butter by churning the warm emulsion. The emulsion breaks, the aqueous phase is drained off, and a water-in-oil emulsion is formed, with water droplets (approximately 18%) dispersed throughout the butterfat.

FACTORS AFFECTING EMULSION STABILITY

- Type of emulsifier
- Concentration of emulsifier
- Droplet size
- Changing pH or ionic strength
- Viscosity
- Addition of stabilizers
- Heating, cooling, freezing, and/or shaking

FOAMS

Foams make a vital contribution to the volume and texture of many common food products. They give volume and a distinctive mouthfeel to products such as whipped cream and ice cream and they give a light, airy texture to baked goods. Improperly formed or unstable foams result in dense products with a low volume, which are unacceptable to consumers. Foams are inherently unstable and it is imperative that food scientists increase their knowledge of the factors affecting foam stability, in order to enhance the quality and shelf life of these products.

A foam contains gas bubbles dispersed in a liquid continuous phase. The liquid phase may be a simple dispersion, as in egg white, which is a dilute protein dispersion, or it may be complex, containing emulsified fat droplets, ice crystals, and/or solid matter. Examples of complex food foams include ice cream, angel food cake, marshmallows, and yeast-leavened breads. Foams such as meringue and baked goods are heat set, which denatures the protein and converts the liquid phase to a solid phase. This gives permanence to the foam structure.

Comparison between Foams and Emulsions

Foams are similar to emulsions, in that the gas bubbles must be protected by a stable interfacial film otherwise they will burst. Therefore, the factors affecting emulsion formation and stability also apply to foams, and in general good emulsifying agents also make good foaming agents. However, there are some important differences between emulsions and foams. The bubbles in foams generally are much bigger than the droplets in emulsions, and the continuous phase surrounding the gas bubbles is very thin. In fact, it is the continuous phase that has colloidal dimensions, rather than the dispersed phase. The density difference between the two phases is much greater in a foam, and there is a tendency for the liquid continuous phase to drain due to gravity and for the gas bubbles to escape. The factors affecting formation are similar for both emulsions and foams. However, there are additional factors involved in foam stability.

Foam Formation

In order to produce a foam, energy must be supplied (by whipping) to incorporate gas into the liquid, to break up large bubbles into smaller ones, and to spread the liquid phase around the gas bubbles as they form. The foaming agent, which is contained in the liquid phase, adsorbs at the surface of the liquid, reducing surface tension and also forming a film around the gas bubbles. It is important that the surface tension is low, so that the liquid will spread rapidly around the gas bubbles during whipping. If newly formed gas bubbles are not immediately coated with foaming agent, they will burst or coalesce and be lost. The amount of energy supplied during whipping also is important; the higher the energy, the smaller the bubbles and the greater the foam volume, provided that sufficient foaming agent is present to completely coat and stabilize the bubbles.

Foam Stability

The stability of a foam may be measured in terms of loss of foam volume over a period of time. When a liquid is whipped to form a foam, the volume of the liquid increases due to incorporation of air. If the foam is stable, the volume does not change very much. However, loss of air from an unstable foam may cause a considerable reduction in volume.

Foam stability may be *reduced* due to the following factors:

- The tendency of the liquid film to drain due to gravity. As it drains, a pool of liquid gathers at the bottom of the container and the film surrounding the gas bubbles becomes very thin. This may allow the gas to escape and the volume of the foam to shrink.
- The tendency for the film to rupture and allow coalescence or escape of gas bubbles.
- Diffusion of gas from small bubbles to larger ones. This results in fewer bubbles and the foam shrinks.

- Evaporation of the continuous phase also affects foam stability, but to a lesser extent. If the liquid evaporates, gas bubbles burst and foam volume is reduced.

If gas bubbles are lost due to any of these factors, a more dense, low-volume foam is produced, which is not usually desirable, especially in foods such as angel food cake or ice cream.

To produce a *stable* foam with a high volume, film rupture, liquid drainage, and evaporation must be prevented or at least minimized. As with emulsions, the gas bubbles must be stabilized by the presence of a stable interfacial layer, which resists rupture. However, the composition of the continuous phase also is very important in determining foam stability. The liquid phase must have a low vapor pressure, so that it does not evaporate readily at storage and handling temperatures. More importantly, drainage of the continuous phase must be minimized. Thick liquids drain more slowly than thin ones and so increasing the viscosity of the continuous phase will reduce drainage. A high viscosity is essential if a stable foam is to be produced.

Foaming Agents

The two most important characteristics of a foam are foam *volume* and foam *stability*. Foam volume depends on the ability of the foaming agent to adsorb at the interface and rapidly reduce interfacial tension and on the level of energy input during whipping. Foam stability depends on the ability of the foaming agent to produce a stable interfacial film and a viscous continuous phase. Although all surfactants are able to reduce surface tension and produce foams, not all are able to form stable foams. In fact, some may act as foam suppressants.

A good foaming agent has the same characteristics as an emulsifier in that it is able to adsorb at the interface, reduce interfacial tension, and form a stable interfacial film that resists rupture. As might be expected, the best foaming agents used in foods are proteins. Although many proteins are able to produce foams, egg white proteins are superior foaming agents and are used in food foams such as meringues, angel, cake, and other baked goods. Other proteins used as good foaming agents include gelatin and milk proteins.

When egg white is whipped (Chapter 10), the proteins denature at the interface and interact with one another to form a stable, viscoelastic, interfacial film. Some of the egg white proteins are glycoproteins containing carbohydrate. When these proteins adsorb at the interface, the carbohydrate sections orient toward the aqueous phase. Being hydrophilic, they bind water and increase the viscosity of the liquid. This helps to reduce drainage, thereby contributing to foam stability.

Gelatin is a good foaming agent, and a warm gelatin sol can be whipped to three times its original volume. When cooled, the gelatin solidifies or forms a gel, which traps the air bubbles and stabilizes the foam; marshmallows are gelatin foams.

The Effect of Added Ingredients on Foam Stability

Many food foams have additional ingredients added to *enhance stability*. For example, egg white foams, such as meringue or angel food cake, also have sugar added. The *sugar* increases the viscosity of the liquid, aiding stability. It also protects the proteins from excessive denaturation and aggregation at the interface. Too much interaction results in an inelastic film that is not resistant to rupture and in reduced foam volume. Therefore, it is important to guard against this when making egg white foams.

Factors Affecting Foam Stability

- Drainage of the liquid film between gas bubbles
- Rupture of the interfacial film around gas bubbles
- Diffusion of gas from small to large bubbles
- Evaporation of the continuous phase

Factors Promoting Foam Stability

- Stable viscoelastic surface film
- Very viscous continuous phase
- Low vapor pressure liquid

Effects of Added Ingredients

Foam Stabilizers	**Foam Destabilizers**
Gums	Lipids
Thickeners	Phospholipids
Sugar	Small molecule surfactants
Acid	Salts
Solid particles	

Acid, such as cream of tartar or lemon juice, also may be used to increase foam stability. Addition of acid reduces the pH, which reduces the charge on the protein molecules and usually brings them closer to their isoelectric point. This generally results in a stronger, more stable interfacial film. When added to egg whites, acid prevents excessive aggregation at the interface. However, acid delays foam formation. It therefore may be added toward the end of the whipping process. In the case of egg whites, it often is added at the “foamy” stage. Whipping is not complete until the egg whites have formed soft peaks. (Egg white foams are discussed in more detail in Chapter 10.)

Other ways to increase viscosity of the continuous phase include addition of *gums* and other *thickening agents*. Also, addition of *solid matter* may promote stability. Whipped cream, for example, is stabilized by solidified fat globules that are oriented in the continuous liquid film. The emulsified fat increases viscosity and is responsible for the stability of whipped cream. To form a stable foam, cream to be whipped must contain at least 30% fat. Creams with lower fat contents may be whipped successfully if thickening agents such as carrageenan are added. If the cream is warm and too much of the butterfat is liquid, then whipping will not produce a stable foam. Instead, the emulsion will break and the cream will be converted to butter.

Ice cream is another example of a complex foam, which is stabilized by emulsified fat droplets and small ice crystals oriented within the continuous phase. Angel food cake contains solid particles in the form of flour, which are folded into the egg white/sugar foam. The flour contributes to stability by increasing the viscosity of the liquid, which minimizes film drainage. The increased viscosity and presence of solid particles also reduces breakage of the interfacial film, hence minimizing loss of foam volume.

Antifoaming Agents and Foam Suppressants

As all cooks know, egg whites will not whip to a stable foam if there is any egg yolk present (Chapter 10). This is because the phospholipids and lipoproteins in the yolk adsorb at the surface, in competition with the egg white proteins, and interfere with formation of a stable egg white protein film. Unlike the egg white glycoproteins, which are hydrophilic, the phospholipids and lipoproteins are unable to increase the viscosity of the continuous phase because they are hydrophobic and so orient away from the water. This prevents formation of a stable foam.

Such molecules are termed ***foam suppressants***. They suppress foam volume because they adsorb at the interface, thus suppressing adsorption of the desired foaming agent and preventing it from forming a stable foam. They do not have the properties required to form a stable film or to sufficiently increase the viscosity of the continuous phase. Hence, their presence makes formation of a stable foam impossible. Typical foam suppressants include fats, phospholipids, and other small amphiphilic molecules.

Salts also tend to act as foam suppressants because they weaken interactions between the protein molecules at the surface, thus weakening the interfacial film around the gas bubbles. However, their effect is not as important as surfactant molecules because they do not adsorb at the interface.

Antifoaming agents are able to break up foams or prevent them from forming. Antifoaming agents are added to fats and oils used in frying to prevent foaming during the frying process. Like foam suppressants, they act by adsorbing at the air/liquid interface in place of the foaming agents, and because they do not have the characteristics of a foaming agent they prevent foam formation.

CONCLUSION

Food emulsions and foams are complex colloidal systems, and understanding their formation and stability is important if the quality and shelf life of these products is to be improved. Emulsions contain liquid droplets stabilized by an interfacial layer of emulsifier and dispersed throughout a liquid continuous phase. Foams are similar, but the dispersed phase consists of large gas bubbles surrounded by a very thin, continuous, liquid film. The nature of the emulsifier or foaming agent is crucial in determining stability. It must adsorb at the interface, reduce surface tension, and form a stable, viscoelastic interfacial layer that resists rupture, so that coalescence of liquid droplets or loss of gas bubbles is avoided. Additional factors are important in foam stability; it is important that the liquid film between the gas bubbles is very viscous, so that drainage due to gravity is minimized. Evaporation of the liquid also must be prevented during normal storage and handling conditions.

Both natural and synthetic emulsifying agents are available to food companies. The best emulsifiers and foaming agents are proteins. Egg yolk proteins are known as the best emulsifiers, whereas egg white proteins are considered to be the best foaming agents used in food products.

GLOSSARY

Adsorb: To bind to a surface.

Amphiphilic: A molecule containing both hydrophobic and hydrophilic sections.

Coalescence: Two liquid (or gas) droplets merge to form one larger droplet.

Colloidal system: Emulsions, foams, dispersions (or sols) and gels are all colloidal systems. A colloidal system contains one phase (usually the dispersed phase) with dimensions ranging mainly from 0.1 to 10 μm. The dispersed phase contains large numbers of small droplets or particles, and so the surface or interfacial area of this phase is very large. This is an important characteristic of colloidal systems.

Continuous phase: The phase or substance that surrounds the liquid droplets or gas bubbles in an emulsion or foam.

Dispersed phase: The discrete bubbles (air, carbon dioxide, or liquid) that are surrounded by liquid in an emulsion or foam.

Emulsifier: A substance that enables two normally immiscible liquids to be mixed together without separating on standing.

Emulsion: An emulsion contains liquid droplets stabilized by a layer of emulsifier and dispersed throughout a liquid continuous phase.

Foam: A foam contains gas bubbles coated with a stable interfacial layer and surrounded by a thin, viscous liquid continuous phase. In food foams, the gas is usually air or carbon dioxide.

Foaming agent: A molecule that is able to promote foam formation. Useful foaming agents in foods also are able to promote foam stability by forming a stable interfacial layer and also by increasing the viscosity of the continuous phase.

Foam suppressant: A molecule that prevents or hinders foaming, generally by adsorbing to the interface in place of the desired foaming agent and interfering with the action of the foaming agent.

Hydrophilic: Water-loving; hydrophilic molecules are either charged or polar and have an affinity for water.

Hydrophilic/lipophilic balance, or HLB: A scale that goes from 1 to 20 and indicates the ratio of hydrophilic and hydrophobic groups on a molecule. It is used to determine the suitability of emulsifiers when formulating an emulsion. A high HLB indicates a molecule with more hydrophilic groups, which is suitable for o/w emulsions. A low HLB indicates that there are more lipophilic groups and the molecule has a greater affinity for oil and is more suited for w/o emulsions.

Hydrophobic: Water-hating; hydrophobic molecules are nonpolar and have an affinity for apolar solvents.

Interfacial tension: The force required to increase the interfacial area of a liquid or to spread it over a surface such as oil. See also surface tension.

Lipophilic: Fat-loving or water-hating. Lipophilic molecules are nonpolar and have an affinity for lipids and other apolar solvents.

Oil-in-water, or o/w emulsion: An emulsion containing oil droplets dispersed in water. Oil is the dispersed phase and water is the continuous phase.

Permanent emulsion: A stable emulsion that does not separate over time.

Surface tension: The force required to increase the surface area of a liquid or to spread it over a surface. Surface and interfacial tension often are used interchangeably. Generally, surface tension applies at the surface of a liquid (ie, when it is in contact with air), whereas interfacial tension applies when two liquids are in contact with each other.

Surface active: A molecule that adsorbs at the surface of a liquid. Surface active molecules contain both hydrophobic and hydrophilic sections and it is energetically favorable for them to exist at the interface rather than in the bulk phase of a liquid.

Surfactant: A surface-active molecule.

Temporary emulsion: An unstable emulsion, which separates into two layers on standing.

Viscoelastic: Exhibits both viscous (liquid) and elastic (solid) properties. In other words, the material will flow if force is applied, but it also will stretch. When the force is removed, the material does not return completely to its original position. It is important for an emulsifier film to flow around droplets to cover temporary bare patches and also to be able to stretch, so that when disrupted, it does not break.

Water-in-oil, or w/o emulsion: An emulsion containing water droplets dispersed in oil. Water is the dispersed phase and oil is the continuous phase.

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PART V

Sugars

CHAPTER 14

Sugars, Sweeteners, and Confections

INTRODUCTION

Sugars are simple carbohydrates classified as *monosaccharides* or *disaccharides* (Chapter 3). The common granulated or table sugar is the dissacharide sucrose, made of glucose and fructose. This chapter on sugars, sweeteners, and confections examines the sources, roles, and properties of sugars, the various types of nutritive sweeteners, and sugar substitutes added to foods. Confections and factors influencing candy types are covered. Sugar should be used sparingly in the diet, and depending on serum glucose and lipid goals, nutritive sweetener intake should be individualized by consumers.

SOURCES OF SUGAR

Table sugar comes from two sources. It naturally exists as syrup in the *sugar cane* or in *sugar beet*, both of which are *identical* in chemical composition. Sugar cane has been used for centuries. It is washed, shredded, pressed, and heated, and the extracted juice is centrifuged to create raw sugar with its slightly brown color. As the juice is centrifuged, molasses separates from the crystals and becomes a by-product of sugarcane sugar production. The crystals then are further refined for uses in various forms.

Roots of the beet are less frequently used to produce sugar and were first extracted in the 1790s. They too are washed, shredded, and so forth. Then roots are treated with lime to remove impurities and further refined to yield usable sugar.

ROLES OF SUGAR IN FOOD SYSTEMS

The roles of sugars are diverse (some are listed below). Sugar may be utilized in *trace* amounts or it may be the *primary* ingredient of a formulation. Sugar imparts sweetness, tenderness, and browning; is hygroscopic (water retaining);

and functions in various other ways in food systems, as may be seen in the following examples of sugar function.

Sweetness

Sugar provides flavor appeal to foods, and therefore is incorporated into many foods. It is a significant ingredient of candy, many baked goods, and frostings as well as some beverages and may be used in a less significant manner or not at all in other foods. Around the world there is an *innate* desire for sweetness. Some individuals consume fruit “picked off of a tree,” while others consume snacks they ”pick out from the office vending machine.”

Tenderness

A batter/dough formula *with* sugar is *more* tender than one *without* sugar, because sugar binds with each of the two proteins gliadin and glutenin and absorbs water so they do *not* form gluten.

Browning

Browning in some varieties of *fruits and vegetables* is due to *enzymatic, oxidative browning*. Sugar also browns and imparts color to foods by two types of *non*enzymatic browning, including (1) the low temperature Maillard browning reaction, and (2) high temperature caramelization.

Maillard browning involves the reaction of the carbonyl group of a reducing sugar with the amine group of an amino acid and occurs with *low* temperature heat, a high pH, and low moisture. Maillard browning is responsible for the color changes that occur in many baked breads, cakes, and pie crusts, canned milks, meats, as well as caramel candies (which, although the name is used, is *not* caramelization).

Caramelization is a *non*enzymatic browning process that occurs in sugars heated to *high* temperatures. As sugar is heated to temperatures above its melting point [338°F (170°C)], it dehydrates and decomposes. The sugar ring (either pyranose or furanose) opens and loses water. The sugar becomes brown, more concentrated, and develops a caramel flavor as it continues to increase in temperature. The dessert flan is an example.

CULINARY ALERT! Caramelization in culinary terms refers to any sugar in food that is broken down to produce enhanced color and flavor upon reaching a high temperature. Most notable is caramelized, dark brown onions.

Other Roles of Sugar in Food Systems beside sweetness, tenderness, and browning (not all-inclusive)

- Functions as a *separating agent* to prevent lump formation in starch-thickened sauces (Chapter 4)
- *Reduces starch gelatinization* (Chapter 4)

- *Dehydrates* pectin and permits gel formation in jelly-making (Chapter 5)
- Stabilizes *egg white foams* (Chapter 10)
- Raises the coagulation temperature of protein mixtures (Chapter 10)
- Adds *bulk* and body to foods such as yogurt (Chapter 11)
- Helps *aerate* batters and dough (Chapter 15)
- Reduces gluten structure by competing with gliadin and glutenin for water, thus increasing *tenderness* (Chapter 15)
- Acts as the substrate that *ferments* to yield CO_2 and alcohol (Chapter 15)
- Adds *moisture retention* properties to baked products
- Maillard *browning*
- Slows/prevents crystallization in candies if invert sugar is used

TYPES OF SUGARS AND SUGAR SYRUPS

Types of sugars "-ose," those used in food preparation, and syrups are discussed below.

- **Sucrose**. Sucrose is the *disaccharide* consisting of the monosaccharides[*] glucose and fructose. It is commonly referred to as "sugar," "white sugar," or "granulated sugar."
- **Fructose**. Fructose is the *monosaccharide* that combines with glucose to form the *disaccharide* sucrose. It is known as fruit sugar, since it is contained in many fruits. Fructose is 1.2–1.8 times as sweet as sucrose.
- **Glucose**. Glucose is the *monosaccharide* that combines with fructose to form sucrose, with galactose to form lactose, and with another glucose to form the *disaccharide* maltose.
- **Galactose**. Galactose is the *monosaccharide* that combines with glucose to form the disaccharide lactose.
- **Lactose**. Lactose is a *disaccharide* (a glucose and galactose molecule) known as milk sugar. It is less sweet than sucrose.
- **Maltose**. Maltose is a *disaccharide* (two glucose molecules) formed by the hydrolysis of starch.

Recipe Preparation May Require These Sugars

Brown sugar. Brown sugar has a molasses film on the sugar crystals, which imparts the brown color and characteristic flavor of this sugar. It contains approximately 2% moisture and requires storage protection against moisture loss.

Confectioners' sugar. Confectioners sugar (confectionery sugar) also is called *powdered sugar* and is derived from either sugar cane or the sugar beet. Sugar

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[*] All monosaccharides contain a free carbonyl group and are reducing sugars, as is the disaccharide maltose.

grains are pulverized by machine to change the sugar grain to a powdered substance and form such sugars as “6X sugar” (pulverized 6 times to create “very fine”), “10X sugar” (pulverized 10 times to form “ultra fine”), and so on. Confectioners’ sugar typically contains 3% cornstarch to prevent caking.

Invert sugar. Invert sugar is created when sucrose is treated by acid or enzyme to form an equal amount of fructose and glucose. It is more soluble and sweeter than sucrose, commonly used in confections.

Raw sugar. Raw sugar has a larger grain than ordinary granulated sugar. It is 97–98% sucrose. It is *not* approved by the FDA for sale in the United States since impurities and contaminants remain in the granule.

Turbinado sugar. Turbinado sugar is raw sugar with 99% of the impurities and most of the by-product of sugar crystal formation (molasses) removed.

Syrups (Liquids)

The conversion of starch yields dextrose (glucose). Syrups then are measured as dextrose equivalents (DE). Syrups may have a DE of 36–55. More pure glucose yield is 96–99 DE.

Corn Syrup. Corn syrup is a mixture of carbohydrates (glucose, maltose, and other oligosaccharides) formed from the hydrolysis of cornstarch by the use of acid or enzymes (HCl, or α and β amylases). Following hydrolysis, it is subsequently refined and concentrated. The sugar solution contains approximately 25% water and is viscous.

$$\boxed{\text{Starch} + \text{Water} \xrightarrow[\text{enzymes}]{\text{acid+heat}} \text{Dextrins} + \text{Maltose} + \text{Glucose}}$$

Corn syrup, due to its high glucose content, more readily participates in Maillard reactions (browning at lower temperatures due to proteins, sugars and nonacidic environment) than other sugars.

High-Fructose Corn Syrup (HFCS). HFCS is a specialty syrup prepared by the same three steps as corn syrups—it is hydrolyzed, refined, and concentrated. In addition, isomerization occurs whereby the principal sugar, glucose, is made into the more soluble fructose by the enzyme action of another enzyme, isomerase.

The syrup contains approximately 42% fructose and may undergo a fractionation process to further remove glucose and create syrup that is 55 or 90% fructose. HFCS containing 42 and 55% fructose are *generally recognized as safe* (GRAS). Many beverages contain HFCS, and although sugar consumption in the United States may show a downward trend, HFCS is increasingly ingested.

Honey. Honey is made from the nectar of various flowers, and therefore differs in color, flavor, and composition. It contains approximately 20% water and a mixture that is glucose and fructose (predominantly the latter), with no more than 8% sucrose. Due to the hygroscopic property of fructose, the addition of honey to a formulation favorably increases its level of moisture.

Darker-colored honey is *more* acidic and *more* strongly flavored than light-colored honey. The strains of alfalfa and clover honey, commonly sold in the United States, are mild-flavored honey. "Strained honey" is honey from a crushed honeycomb that is strained.

Maple Syrup. Maple syrup is obtained from the sap of the maple trees. The sap is boiled and evaporated, and the final product contains no more than 35% water (40 parts sap = 1 part maple syrup).

Molasses. Molasses is the syrup (plant juice) separated from raw sugar beet or sugar cane during its processing into sucrose, and thus it is a by-product of sugar making. The predominant sugar is sucrose, which becomes more invert sugar with further processing. Molasses provides very low levels of the minerals, calcium and iron, although blackstrap molasses is the product of further sugar crystallization and contains a *slightly* higher mineral content.

The Sugar Association states almost 60% of sweetener intake is from corn sweeteners, especially in sodas and sweetened drinks. The other 40% is from table sugar or sucrose.

PROPERTIES OF SUCROSE

Properties of sucrose, in addition to supplying sweetness, are important in food systems, such as confections. These are discussed in the following subsections.

Solubility

Solubility of sugars varies with sugar type. For example, sucrose is more soluble than glucose and less soluble than fructose. This influences candy type and product success (see Formation of Invert Sugar).

In its dried, granular form, sugar becomes *increasingly* soluble in water with an increase in temperature. At *room temperature* water is capable of dissolving sucrose in a ratio of 2:1 (67% sucrose and 33% water). If that same water is *heated*, more sugar is dissolved, and as the sugar–water is further heated and brought to a boil, water evaporates and the sugar syrup becomes increasingly concentrated. This is seen in the amount of sugar held by equal amounts of iced tea and hot tea beverages. Hot tea holds more dissolved sugar.

Sugar may precipitate from solution, forming an undesirable grainy, crystalline product. Therefore, to increase the solubility of sucrose and reduce possible undesirable crystallization, sucrose may be treated by inversion to become *invert sugar*.

Types of Solutions

Solutions are the homogeneous mixtures of ***solute***, dissolved in ***solvent***. Depending on the amount of dissolved solute that the water is holding at any specific temperature (see Sugar Concentration), solutions may be dilute (unsaturated), saturated, or supersaturated.

TABLE 14.1 Boiling Point of Sucrose–Water Syrups of Different Concentrations[a]

Percent of sucrose in syrup	Percent water	Boiling point in °F (°C)	
0 (all water, no sugar)	100	212	(100)
20	80	213.1	(100.6)
40	60	214.7	(101.5)
60	40	217.4	(103)
80	20	233.6	(112)
90	10	253.1	(123)
95	5	284	(140)
99.5	0.5	330.8	(166)

[a] At sea level.

Elevation of Boiling Point

The boiling point of sugar *elevates* with *increasing concentrations of sucrose* in solution as shown in Table 14.1. The boiling point also rises as the liquid evaporates from a boiling solution and causes there to be a greater concentration. This more concentrated solution now has a reduced vapor pressure that elevates boiling point because more heat is needed to raise the reduced vapor pressure found in a more concentrated sugar solution.

The addition of sugars other than sucrose, as well as the addition of interfering agents, *also elevates the boiling point*. At sea level water boils at 212°F (100°C). For every gram molecular weight of *sucrose* that is dissolved in water, there is a 0.94°F (0.52°C) increase in boiling point. This is why sugar solutions reach a very high temperature and cause more severe burns than boiling water.

CULINARY ALERT! High elevation lowers boiling point. For each 500 feet in elevation above sea level, there is progressively less atmospheric pressure and the boiling point *decreases* 1°F. [Therefore, at an elevation of 5,000 feet, the boiling point is *lowered* by 10°F, to 202°F (94°C).] The boiling point is *lowered* 1°C (1.8°F) for each 960 ft above sea level.

Formation of Invert Sugar

Another property of sugar is that *invert sugar* is formed by sucrose hydrolysis in the process of ***inversion***. It yields equal amounts of the monosaccharides *glucose* and *fructose* and the latter is more soluble than sucrose (fructose > sucrose > glucose).

CULINARY ALERT! Due to increased solubility, the use of invert sugar in confections is desirable in candies to slow crystallization and to help keep crystals small. Invert sugar is combined in a ratio of 1:1 with sucrose in many product formulations to control crystal formation and achieve small crystals.

As shown in the formula, sucrose may be hydrolyzed into invert sugar by either *weak acids*, such as in cream of tartar (the acid salt of weak tartaric acid), or by *enzymes*, such as invertase. Each is described below.

$$\underset{\text{Sucrose}}{C_{12}H_{22}O_{11}} + \underset{\text{Water}}{H_2O} \xrightarrow[enzyme]{acid+heat} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6}$$

In *acid hydrolysis*, it is both (1) the amount of acid, and (2) the rate and length of heating that determines the quantity of invert sugar that forms. This is addressed below:

- *Amount of acid*: *Too much* acid, such as cream of tartar, may cause *too* much hydrolysis, which forms a soft or runny sugar product.
- *Rate and length of heating*: A *slow* rate and slow attainment (long length of heating) of the boiling point increases inversion opportunity, whereas a *rapid* rate provides less inversion opportunity.

In *enzyme hydrolysis*, sucrose is treated with the enzyme invertase (also known as sucrase) to form glucose and fructose.

CULINARY ALERT! Enzyme hydrolysis may take several days, as is the case with invert sugar that is responsible for forming the liquid in chocolate-covered cherries.

The *glucose* that forms from inversion is *less* sweet than sucrose and the *fructose* is *more* sweet, with the overall reaction producing a sweeter, more soluble sugar than sucrose. Invert sugar is combined in a ratio of 1:1 with untreated sucrose in many formulations to control crystal formation and achieve small crystals.

Hygroscopicity

Hygroscopicity, or ability to readily absorb water, is a property of *sucrose*. However, other sugars that are high in *fructose*, such as *invert sugar*, *HFCS*, *honey*, *or molasses*, are *more* hygroscopic than sucrose. It therefore is important to control the degree of inversion that these sugars undergo or they may exhibit *runny* characteristics in storage.

Sugar that is stored in a *humid storeroom* location or candy that is prepared on a *humid day* are *both* situations that demonstrate this property of hygroscopicity in that the sugar becomes lumpy and the candy is soft. (This hydroscopicity property of sugar carried caution for the preparation of meringues in Chapter 10.)

Moisture-proof containers are recommended for the storage of sugar and sugar products. Due to this hygroscopic property of sucrose, product developers may *encapsulate* or coat sugars, so that sugars are time-released, which prolongs the sweetness perception and allows sucrose to withstand expected processing conditions (1).

Fermentable

Another property of sugar is that sugar is fermentable. It undergoes ***fermentation*** by the biological process in which bacteria, mold, yeast, and enzymes anaerobically convert complex organic substances, such as sucrose, glucose, fructose, or maltose, to *carbon dioxide* and *alcohol*.

SUGAR SUBSTITUTES

Americans consume sugar items such as cereals, cakes, pies, ice cream, soda, and candies. The Calorie Control Council reported in a 1998 survey that Americans regularly consume low-calorie, sugar-free sugar substitutes in order to cut back on calories. Sugar substitutes include the two categories of (1) *artificial sweeteners* (noncaloric, nonnutritive) sweeteners, and (2) *sugar alcohols* (caloric, nutritive). Some examples of sugar substitutes are identified in the following subsections.

Artificial or High-Intensity Sweeteners

Artificial sweeteners or high-intensity sweeteners are one category of sugar substitute. They are noncaloric, nonnutritive, intense sugar substitutes, whose use has grown in response to increased consumer demand. They must be FDA approved before use. Some examples of artificial sweeteners are as follows.

- **Acesulfame K**. *Acesulfame potassium* (Acesulfame K) is a noncaloric, synthetic derivative of acetoacetic acid that received FDA approval in 1988. It is an organic salt consisting of carbon, hydrogen, nitrogen, oxygen, potassium, and sulfur and is *not* metabolized by the body but is rather excreted *un*changed. It is 200 times (thus high intensity) sweeter than sucrose and is heat stable; thus, it may be used for baking and cooking purposes in addition to use as a tabletop sweetener.

  Acesulfame K has no bitter aftertaste and may be used *alone or in combination* with the sweeteners saccharin or aspartame (Figure 14.1). Some brand name examples of acesulfame K are Sunette®, Sweet One®, Swiss Sweet®, and Nutra Taste®.

  CULINARY ALERT! *Sweet One® 12 packets = 1 cup sugar.*

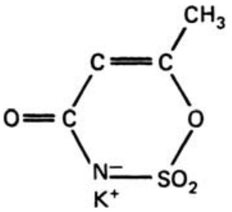

FIGURE 14.1 Chemical structure of acesulfame K.

- **Aspartame**. *Aspartame* is a *nutritive* sweetener that contains the *same* number of calories per gram as sugar (4 calories/gram). However, because it is much sweeter and used in minute amounts, it is *not* a significant source of either calories or carbohydrates and is often put in the category of nonnutritive, noncaloric sweeteners. It is a methyl ester comprising two amino acids: aspartic acid and phenylalanine. Thus because of the latter, it should *not* be consumed by those with the genetic disease phenylketonuria (PKU) because it contains phenylalanine, which is *not* metabolized (Figure 14.2).

  Aspartame is one of the most thoroughly tested and studied food additive the FDA has ever approved (FDA). It gained FDA approval in 1981 and is 180–200 times sweeter than sucrose. It is marketed under the trade name NutraSweet®, and Equal® is the tabletop low-calorie sweetener with NutraSweet®. Aspartame was *not* originally intended for use in heated products; however, it may be encapsulated in hydrogenated cottonseed oil with a time–temperature release, which makes its inclusion in baked products acceptable.

  CULINARY ALERT! *Equal® 24 packets = 1 cup sugar.*

- **Saccharin**. *Saccharin* is a noncaloric substance produced from methyl anthranilate, a substance naturally found in grapes. It has been used as a noncaloric sweetener since 1901 in the United States, and is 300–700 times sweeter than sucrose.

  The use of saccharin was periodically reviewed as specified by US Congress in the *Saccharin Study and Labeling Act*. The ruling required that foods containing saccharin must be labeled to read as follows: "Use of this product may be hazardous to your health. This product contains saccharin which has been determined to cause cancer in *laboratory animals*."

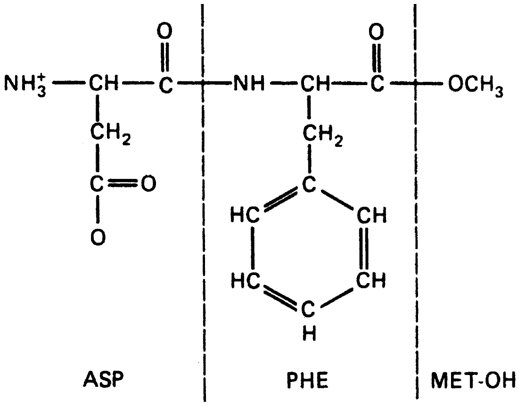

FIGURE 14.2 Chemical structure of aspartame. ASP, aspartic acid; PHE, phenylalanine; MET-OH, methyl alcohol.

Yet, following a moratorium on banning saccharin, which was extended by Congress several times pending further safety studies, it was shown that saccharin has *not* demonstrated any carcinogenicity applicable to *humans*. Therefore, after several decades the safety of saccharin has been shown and the use of a warning label is *no* longer required. The use of saccharin has been reported to be acceptable by the American Medical Association, the American Cancer Society, and the American Dietetic Association.

In December 2000, Congress passed HR 5668—the **s**accharin **w**arning **e**limination via **e**nvironmental **t**esting **e**mploying **s**cience and **t**echnology (SWEETEST) Act. It is approved for use in more than 100 countries.

Calcium or sodium saccharin, combined with dextrose (nutritive, glucose) and an anticaking agent, may be used in tabletop sweeteners. Saccharin may be used in combination with aspartame. Brand-name examples include Sweet 'N Low®, Sugar Twin®, Necta Sweet®, and Sweet-10®.

CULINARY ALERT! *Sweet 'N Low® 12 packets = 1 cup sugar.*

- **Sucralose**. *Sucralose* gained FDA approval in 1998 for use in 15 food and beverage categories, including baked goods and baking mixes; beverages and beverage mixes; chewing gum; coffee and tea; confections and frostings; dairy product analogs; fats and oils (salad dressings); frozen dairy desserts and mixes; fruit and water ices; gelatins, puddings, and fillings; jams and jellies; milk products; processed from it and fruit juices; sweet sauces, toppings, and syrups; and sugar substitutes. It is a *noncaloric* trichloro derivative of sucrose [three hydroxyl (hydrogen–oxygen) groups on a sugar molecule are selectively replaced by three atoms of chlorine], plus maltodextrin, which gives it bulk and allows it measure cup-for-cup like table sugar. It is 400–800 times sweeter than sucrose.

  Several advantages to its approval are that (1) it is the only *noncaloric* sweetener made from sugar; (2) it is *stable* under a wide range of pH, processing, and temperature scenarios; for example, it is water- and ethanol-soluble, and heat stable in baking and cooking; and (3) it carries *no health warnings*. Splenda® is the brand name under which sucralose is marketed (Figure 14.3).

CULINARY ALERT! *Splenda® 1 cup = 1 cup sugar.*

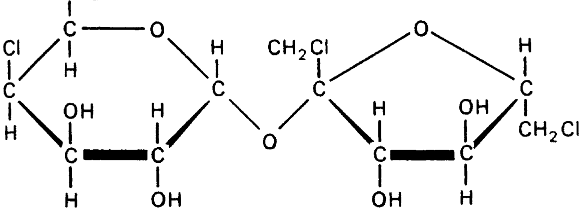

FIGURE 14.3 Chemical structure of sucralose.

- **Cyclamate**. Cyclamate does not have FDA approval. It was in use in 1960s, but banned in the United States in 1970. Currently, the FDA is considering a petition for reapproval, as evidence of its connection with bladder cancer is not verified. It is noncaloric and 30 times sweeter than sucrose.
- **Neotame**. FDA approval in 2002.

Sugar Alcohols (Polyols)

A type of sugar substitute with a *distinct* classification from artificial sweeteners is *sugar alcohol*. Sugar alcohols are *caloric*, chemically reduced carbohydrates (slightly less calories than sugar) that provide sweetness to foods.

The sugar alcohols are similar in chemical structure to glucose, but an alcohol group replaces the aldehyde group of glucose. Among others, this classification includes:

- *Sorbitol*, which is commercially produced from glucose and contains 2.6 cal/g.
- *Mannitol*, which contains 1.6 cal/g.

Both these sugar alcohols provide half the sweetness of sucrose and may be used as *humectants* (Chapter 18) because they increase the water-holding capacity of the food. Sorbitol also is used as a bulking agent. In *combination* with aspartame and saccharin, it provides the volume, texture, and thick consistency of sugar.

Xylitol, Isomalt, hydrogenated starch hydrolysate (HSH), and hydrogenated glucose syrup (HGS) are other sugar alcohols. Isomalt is 45–65% as sweet as sucrose; 2 cal/g are in HSH and HGS has 3 cal/g.

These may be *sugar free*, however, they are *not calorie-free*! The body does not metabolize sugar alcohols, so persons with diabetes may use sugar alcohols without a rise in their blood sugar. Large amounts of sugar alcohols may cause intestinal diarrhea; therefore, they are not recommended for use in significant amounts.

CONFECTIONS

The term "*confections*" has several uses and meanings. For example, chocolates may be known as "*chocolate confectionery*," cakes and pastries may be referred to as "*flour confectionery*," and the term "*sugar confectionery*" may signify any sugar-based products. Sweet food products may utilize the terms "confections" or candy. However, in the United States, both chocolates and the various sugar-based confections are simply referred to as "candy."

CULINARY ALERT! Sugar syrups have a very high temperature and can cause severe skin burns.

Candy-making primarily is dependent on the *concentration* of sugar in boiled sugar syrups and on *controlling or preventing crystal formation*. Various ingredients, such as gelatin, fruit, nuts, milk, acids and so forth, in addition to sugar, may be added to produce specific candies.

Sugar substitutes are not generally used for candy-making. Since they are used in small quantities and cannot add bulk to candy formulation/recipes and due to the fact that they do not crystallize, they do not produce satisfactory results in all candies. Real sugar may be necessary as a major recipe ingredient in candy-making.

In the preparation of candies, the sugar solution must be ***saturated***—holding the *maximum* amount of dissolved sugar it is capable of holding at the given temperature needed for the specific candy type. Upon cooling, the solution becomes ***supersaturated***—holding *more* dissolved sugar than theoretically it can hold at a given temperature

CULINARY ALERT! High humidity during candy preparation results in excess moisture retention and less than desirable results because a characteristic of sugar is that it is hygroscopic.

Major Candy Types—Crystalline and Amorphous Candies

Two major types of candies are *crystalline and amorphous* candies. Each will be discussed in this chapter section. ***Crystalline*** candies are formed in the process of **crystallization** as heat is given off—***heat of crystallization***. This type of candy has crystals suspended in a saturated sugar solution. Crystals may be *large and glasslike*, as in rock candy, or they may be *small and smooth textured*, breaking easily in the mouth, as in fondant or fudge candies. Crystalline candies have a highly structured crystalline pattern of molecules that forms around a nuclei or seed, and therefore it is required that the sugar mixture for crystalline candies must be left undisturbed (more later) to cool.

Amorphous or *noncrystalline* candies are those *without* a crystalline pattern and include several types as follows:

- Caramel and taffies, are *chewy* amorphous candies.
- Brittles are *hard* amorphous candies.
- Marshmallows and gumdrops are aerated, *gummy* amorphous candies.

In general, amorphous candies contain a *high* sucrose concentration (Table 14.2) and a large amount of agents that interfere with (see Interfering Agents) or prevent crystal formation. They have a low moisture level (the molecular ring opened and water is lost) and are more viscous as syrup than crystalline candies.

Factors Influencing Degree of Crystallization and Candy Type

Crystals are closely packed molecules that form definite patterns around nuclei as a sugar solution is heated and subsequently cooled. Crystal development (crystalline candies) or lack of it (amorphous candies) is dependent on factors discussed in the following text. Such factors include the *temperature, type and concentration of sugar, cooling method*, and *use of added substances* that interfere with crystal development.

TABLE 14.2 Major Candy Types

Candy type	Final temperature in °F	(°C)	Percent sucrose
Crystalline			
Fudge	234	(112)	80
Fondant	237	(114)	81
Amorphous			
Caramel	248	(118)	83
Taffy	265	(127)	89
Peanut brittle	289	(143)	93

Crystalline formation in a sugar solution occurs due to ***seeding***. It is desirable. Yet seeding may occur prematurely. For example, stray sugar crystals remaining on the side of the pan after stirring may fall later into the mixture in the pan. To prevent this unwelcome addition, use of a *pan lid* is recommended for initial cooking so that all crystals dissolve.

CULINARY ALERT! It is recommended that the pan lid remain on the sugar mix for a few minutes initially so that steam can dissolve stray sugars, thus preventing seeding.

In this section, some factors that influence the degree of crystallization, and thus candy type, are presented.

Temperature. *Temperature* of a sucrose solution is an indication of its concentration. Specific temperature requirements must be met for cooking each type of candy (Table 14.2). If the designated temperature has been *exceeded*, water may be added to the sugar solution in order to *dilute* its concentration and *lower* the temperature. This helpful addition of water is possible only as long as the sugar solution has not yet reached the caramelization stage.

A *slow rate* of achieving the boiling point of a sucrose and water solution is desirable. A slow rate increases the time available for inversion of sucrose, allows increases in the solubility of the sugars, and produces a softer final product compared to *rapid* heating.

CULINARY ALERT! Candy-making temperatures exceed the boiling point of water, and as water evaporates the sugar syrup becomes viscous, causing more severe burns than boiling water if it contacts the skin.

Sugar Type. *Sucrose* molecules are able to align and form large lattice arrangements of crystals. Other sugars, such as the monosaccharides *glucose and fructose* (or invert sugar), possess different shapes that interfere with aggregation and crystal development; (thus, a candy with too much invert sugar will fail to harden and is deemed unsatisfactory). *High-fructose corn syrup, honey, and invert sugar* are examples of sugars that are added to syrup in candy-making in order to *prevent* the formation of large crystals.

Sugar Concentration. As previously mentioned, candy making is dependent on the sugar *concentration*. A sugar solution is *dilute* (unsaturated) if the concentration of a solute is less than maximum at a given temperature. Initially this is true in candy-making. Then, as the sugar solution boils, water evaporates and the solution becomes *saturated*. When the saturated solution is cooled, it becomes *supersaturated* and easily precipitates sugar.

Amorphous candies have a *higher* sugar concentration (Table 14.2) than crystalline candy because more sugar is incorporated and more water has evaporated at the higher temperature. The candy mixture is so viscous that crystals *cannot* form.

Cooling Method and Timing of Agitation/Beating. The cooling method and timing of agitation determine adequacy of crystalline candy. *Crystalline* candy must not be disturbed by *premature* agitation/beating during cooling. *Crystalline* candy is best formed by *slowly* cooling the sugar solution to approximately 100–104°F (38–40°C) *before* stirring or beating. (In reading temperature, stray crystals/seeds are prevented from entering the mixture if the thermometer is free from sugar residue.)

Once cooled to the desirable cooling temperature, the timing is correct and agitation becomes necessary because timely agitation produces/keeps *many small* nuclei in the supersaturated solution. Then, with agitation, excess sugar molecules in the solution are prevented from attaching to already developed crystals. The crystal size remains small.

Amorphous candy is formed from a very supersaturated solution (Table 14.2) and an undisturbed cooling method is *not* crucial for success. The solution is too viscous to allow aggregation of solute molecules and crystal formation.

Interfering Agents. In crystalline products, ***interfering agents*** reduce the speed of crystallization and help to *prevent* undesirable growth of crystal structures that result in the formation of large, crystalline, gritty candies. There are several types of interfering agents:

- *Chemical* interfering agents include *corn syrup or cream of tartar*. Both reduce the quantity of excess sucrose (the solute) available for formation of the crystalline lattice (see Sugar Type, above). Corn syrup contains *glucose* and the acid cream of tartar inverts sucrose to glucose and fructose. These *nonsucrose* molecules (*glucose and fructose*) do not fit properly (are not able to join) onto existing sucrose lattice structures, thereby keeping crystals *small*. Both *small crystals* and the resultant smooth textured candy are produced by the addition of cream of tartar or corn syrup to the solution.
- *Mechanical* interfering agents used in candy-making *adsorb* to the crystal surface and physically *prevent* additional sucrose from attaching to the crystalline mass; thus, crystals are many and small. Some examples of mechanical interfering agents are *fat*, the *fat in milk or cream*, and the *proteins* in milk and egg whites. In *amorphous* products such as caramel, taffy, and peanut brittle, interfering agents prevent crystallization and add flavor.

Factors Affecting Candy Hardness. Candies vary in their moisture content. Moisture in the air and other added ingredients affect candy hardness or softness. A hard candy has 2% moisture; while gummy candy, such as gumdrops, contain 15–22% moisture.

Ripening

Crystalline candies must ripen in order to produce an acceptable candy. Ripening occurs in the initial period of *storage, following* the cooking, cooling, and crystallization of a sugar solution, as the moisture level (sugar is hygroscopic) increases, and small crystals are redissolved in the syrup, preventing unwanted crystallization. Smoothness of the finished candy is desired.

NUTRITIVE VALUE OF SUGARS AND SWEETENERS

Sucrose is a carbohydrate that contains 4 cal/g. It supplies *energy* but *no* nutrients to the body. “Guidelines for use of nutritive sweeteners as a part of a well-balanced diet should be individualized based on a patient’s eating habits along with serum glucose and lipid goals” (1). For example, the diabetic must manage *blood serum glucose* levels, and others watch their levels of *serum lipids* that are adversely affected by large amounts of fructose. “There is nothing unusual about craving sweets . . . Humans have an appetite for sugary things. But in excess, sugary foods can take a toll. Large quantities add up to surplus calories, which can contribute to weight gain.” (FDA)

Sugar substitutes including the nonnutritive, artificial sweeteners, and caloric sugar alcohols may pose adverse health effects for some individuals. If that is the case, intake of that product should be limited or eliminated from the diet. For example, aspartame contains phenylalanine, a substance phenylketonurics are unable to properly rid from their bodies and excessive levels of sugar alcohols may cause diarrhea.

A healthful diet uses sugars sparingly, as high consumption equates to a diet with low nutrient density. “Sugars” that appear on the Nutrition Facts label include 1) the total sugars found *naturally* in foods, and 2) *added sugars*. Labeling criteria require that *all monosaccharides* and *disaccharides* be listed as “sugars” on the Nutrition Facts label, regardless of whether they are a natural part of the food or added to the product. Clarification of natural and added sugars may be determined by reading the foods’ *ingredients* list.

CULINARY ALERT! An example of “sugars” on labels is seen in orange juice, which reports “sugars” on the label, however, does not contain added sugar simply naturally present fruit sugar.

Sugars have a recommended intake of 10% of calories, but no % Daily Value. “Sample dietary patterns recommend limiting total added sweeteners, on a carbohydrate-content basis to no more than 6 tsp/day at 1,600 kcal, 12 tsp/day at 2,200 kcal, and 18 tsp/day at 2,800 kcal . . . 6–10% of energy” (USDA).

The designation “sugar free” signifies that there is less than 0.5 g of sugar per serving. “Reduced sugar” indicates that the food contains 25% less sugar per serving than the regular product. “No added sugar” signifies that the product has no sugar added. Product labels may state that the product is a *reduced-* or it low-calorie food, if the food meets the necessary requirements of those definitions (Chapter 20).

The American Dietetic Association Position Statement with regard to sweeteners is as follows:

> “It is the position of the American Dietetic Association (ADA) that consumers can safely enjoy a range of nutritive and non-nutritive sweeteners when consumed in moderation and within the context of a diet consistent with the Dietary Guidelines for Americans.”

CONCLUSION

Sugar comes from sugar cane or sugar beets, both of which have the same chemical structure. The roles of sugar are many and include providing flavor, color, and tenderness. Sugars elevate boiling point and are soluble in water, hygroscopic, and fermentable. A variety of sweeteners, including sugar substitutes, and syrups are incorporated into food systems to provide sweetness.

In order to control the rate of crystallization and the formation of small crystals and to ensure a smooth texture, interfering agents are incorporated into a sugar formulation. Chemical interfering agents produce invert sugar (glucose and fructose), thereby slowing crystallization and increasing the solubility of solute. Mechanical interfering agents such as fat and protein help to keep crystals small by preventing the adherence of additional sugar crystals onto the nuclei. According to the USDA food pyramid, a healthful diet uses sugars sparingly.

GLOSSARY

Amorphous: Noncrystalline candies without a crystalline pattern; may be hard candies and brittles, chewy caramel and taffies, gummy marshmallows and gumdrops.

Artificial sweetener: Noncaloric, nonnutritive sugar substitute; examples are acesulfame K, aspartame, and saccharin.

Caramelization: Sucrose dehydrates and decomposes when the temperature exceeds the melting point; it becomes brown and develops a caramel flavor, nonenzymatic browning.

Crystalline: A repeating crystal structure; solute forms a highly structured pattern of molecules around a nuclei or seed; includes large crystal, glasslike rock candy, or small crystal fondant and fudge.

Crystallization: Process whereby a solute comes out of solution and forms a definite lattice or crystalline structure.

Fermentation: The anaerobic conversion of carbohydrates (complex organic substances), such as sucrose, glucose, fructose or maltose, to carbon dioxide and alcohol by bacteria, mold, yeast, or enzymes.

Heat of crystallization: The heat given off by a sugar solution during crystallization.

Hygroscopicity: The ability of sugar to readily absorb water; sugars high in fructose such as invert sugar, HFCS, honey, or molasses retain moisture more than sucrose.

Interfering agent: Used in crystalline products to reduce the speed of crystallization and help prevent undesirable growth of large crystal structures; interference is by mechanical or chemical means.

Inversion: The formation of equal amounts of glucose and fructose from sucrose; by acid and heat, or enzymes; invert sugar is more soluble than sucrose.

Maillard browning: Browning as a result of reaction between the amino group of an amino acid and a reducing sugar.

Nuclei: An atomic arrangement of a seed needed for crystalline formation; fat is a barrier to seeding of the nuclei.

Saturated: A sugar solution holding the maximum amount of dissolved sugar it is capable of holding at the given temperature.

Seeding: To precipitate sugar from a supersaturated solution by adding new sugar crystals (the seed may originate from sugar adhering to the sides of the cooking utensil).

Solute: That which is dissolved in solution; the amount of solute held in solution depends on its solubility and the temperature.

Solution: Homogeneous mixture of solute and solvent; it may be dilute, saturated, or supersaturated.

Solvent: Medium for dissolving solute; ie, water dissolves sugar.

Sugar alcohol: Caloric sugar substitute; chemically reduced carbohydrates that provide sweetening; examples are mannitol and sorbitol.

Supersaturated: Solution contains more solute than a solution can hold at a specified temperature; formed by heating and slow, undisturbed cooling.

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PART VI

Baked Products

CHAPTER 15

Baked Products: Batters and Dough

INTRODUCTION

This baked products chapter builds on knowledge of the functional properties of carbohydrates, fats, and proteins. Specific batter and dough ingredients that are discussed are sequenced to include previously studied commodities, such as flour, eggs, milk, fats and oils, and sweeteners. Among other important points, this chapter will view the functions of various ingredients in a *general* manner, and the role of those ingredients in *specific* baked products.

Many baked products contain flour (of course, not flourless cake), especially wheat flour, as the primary ingredient. Baked products vary significantly in their fat and sugar content. Pastries and some cakes are *high* in fat, whereas other cakes such as angel food cake may be *fat-free*.

Batters and *dough* each contain different proportions of liquid and flour, and therefore are manipulated differently—by stirring, kneading, and so forth. The words are not interchangeable. A well-developed gluten protein network is desirable in some products and not in others. The network may hold many additional substances, such as starch, sugar, a leavening agent to produce CO_2, liquid, and perhaps eggs, fats or oils, and so forth. Other items, including salts or acids, also are found in baked products.

The gas cell size and shape as well as its surrounding ingredients create the “grain” and texture of a baked product. Most batters and doughs are “foams” of coagulated proteins around air cells. For example, angel food cakes and sponge cakes form definite foam structures.

A *quick bread* is one that is relatively quick to mix before baking and is leavened primarily by added *chemical* agents, such as baking powder or baking soda, and not by yeast. It may be leavened by steam or air. Pancakes and waffles, biscuits and muffins are examples. *Yeast breads*, on the other hand, are leavened *biologically* by yeast and are not quick, but rather are more time-consuming to prepare.

Ready-to-eat (RTE) and ready-for-baking products continue to replace some baking "from scratch." Low-fat products are popular. Proper storage extends shelf-life.

CLASSES OF BATTERS AND DOUGH

Batters and dough are classified according to their ratio of liquid to flour (Table 15.1), and they each utilize various mixing methods. While exact ingredient proportions of both batters and dough vary by recipe, for use as a planning guide or in recipe analysis, the ratios in Table 15.1 provide useful guidelines.

Batters are flour–liquid mixtures that are *beaten or stirred*, and as shown incorporate a considerable amount of *liquid* as the *continuous medium*. Batters are classified as either pour batters or drop batters. *Pour* batters, such as those batters used in the preparation of items such as pancakes and popovers, are thin and have a 1:1 ratio of liquid to flour. *Drop* batters contain *more* flour than a pour batter with a ratio of 1:2 of liquid to flour. Muffins and some cookies are examples of products prepared with drop batter.

Dough is distinguished by being thicker than batter. It is *kneaded,* not beaten or stirred, and the *flour/gluten matrix*, not liquid (as batters) is the *continuous medium*. The flour mixtures are classified as soft or stiff dough. For example, *soft* dough, such as that used in biscuit preparation or yeast bread have a liquid-to-flour ratio of 1:3. *Stiff* dough may have a ratio of 1:6 or higher and might be used for cookies or pastry dough, such as pie crust.

GLUTEN

Gluten, or the gluten matrix, is noted for its *strong*, three-dimensional, viscoelastic structure that is created by specific proteins. Specifically, it is the hydrophobic, *insoluble gliadin proteins* that contribute *sticky*, fluid properties to the dough and the *insoluble glutenins* that contribute ***elastic*** properties to the dough. Not all flours, and therefore not all dough, forms gluten. Nongluten flours contain *starch* that provides some structure; however, it is *gluten* protein that provides the major *framework* for many batters and dough (Figure 15.1).

TABLE 15.1 Batters and Doughs: Ratio of Liquid to Flour

Type	Liquid	Flour
Batter		
Pour batter	1 part	1 part
Drop batter	1 part	2 parts
Dough		
Soft dough	1 part	3 parts
Stiff dough	1 part	6–8 parts

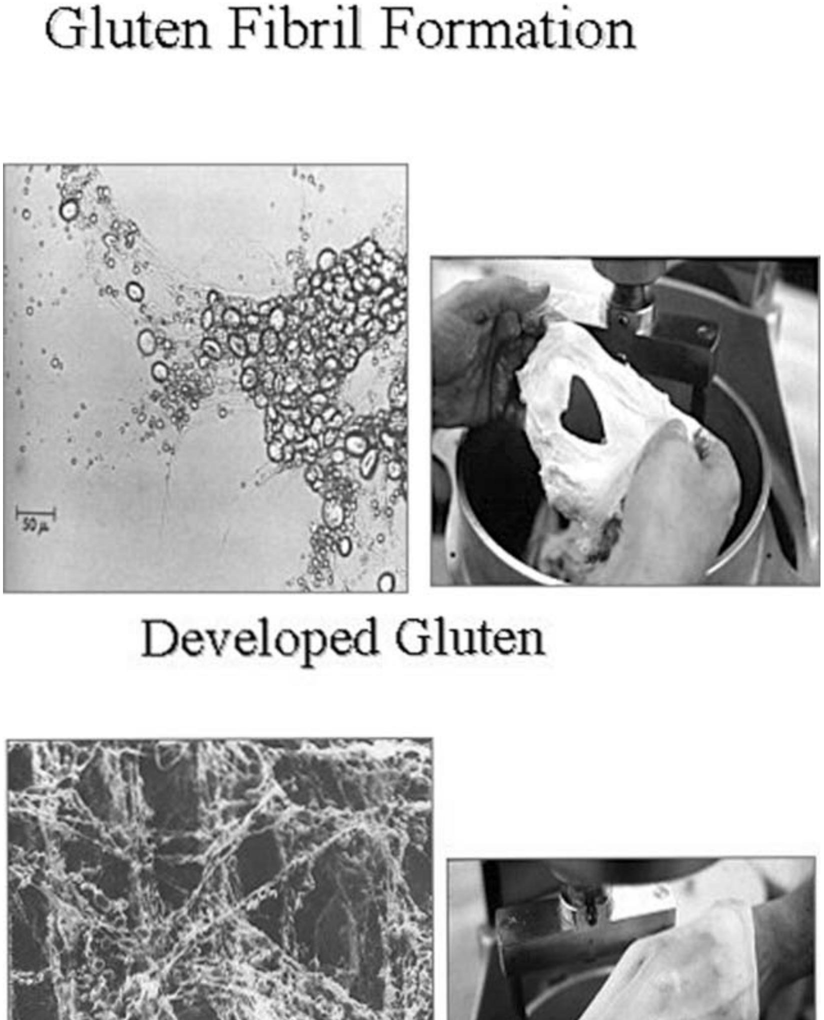

Figure 15.1 Gluten fibril formation (*Source*: Bernardin and Lasarda, 1973).

Upon hydration and manipulation, the two proteins aggregate and form disulfide bridges producing a gluten protein matrix that subsequently is *coagulated* upon baking. This is a three-dimensional structure capable of stretching without breaking, although it may break with overextension if dough is kneaded too much. The gluten determines the texture and volume of the finished product. Oftentimes directions will state: "rest the dough," and to the extent that the dough contains gluten, resting serves to relax the gluten structure.

Many baked products contain flour that is derived from wheat and especially *hard wheat, or oat, rye or barley* (see Chapter 6). These flours have ***gluten-forming potential*** while corn, rice, and soy, do *not* have gluten-forming potential due to inherent differences in protein composition. Yeast breads made with wheat flour are kneaded to create an extensible structure. The dough requires extensive ***gluten development*** to be able to expand. *Without* gluten, the *latter* types of flour listed above are incapable of any structure expansion when CO_2 is generated from yeast.

The gluten structure in the batter/dough mixture is embedded with recipe ingredients such as the starch in the flour, which itself contributes to dough rigidity, added fat or sugar, liquid, or leavening. These added ingredients (see Functions of Various Ingredients in Batters and Dough) influence the development of the gluten structure, the dough strength, and the finished baked product. For example, dough does not reach its maximum strength when the recipe includes high levels of (1) sugar, which competes with gliadins and glutenins for available water, or (2) fat, which *covers* flour particles and prevents water absorption needed for gluten development.

Dough such as biscuit dough has a liquid-to-flour ratio that makes it more likely than *batters* to become tough due to the large proportion of flour. This is true especially if the biscuits are overstirred or kneaded resulting in extensive development of gluten.

Of the *batter* types, *pour* batters do not exhibit a significant difference in gluten development between *adequately mixed* and *overmixed* batter. *Drop* batter, such as a muffin batter, has more flour and a greater chance of developing gluten. If gluten is overdeveloped, batters and dough may exhibit obvious internal holes in a tunnel formation (see Mixing Methods for Various Batters and Dough).

With the use of *less* flour, *less* gluten is likely to be produced. It follows that *sifted* flour also incorporates *less* flour into a recipe, and so there is *less* gluten-forming potential compared to an equal measure of *unsifted* flour. Sifting also incorporates air that provides leavening.

CULINARY ALERT! Specifying “flour, sifted” or “sifted flour” as directions in a product formulation/recipe are two different instructions. Measure first, then sift is the former, sift first, then measure is the latter!

In order to see gluten, manipulated dough must be washed in *cold water* (not hot water as hot will gelatinize starch). This washing removes the nonprotein components of the flour. Then, only the gummy gluten component of flour remains. It resembles already chewed chewing gum! When this gluten ball is subsequently baked, the entrapped water becomes steam and leavens the hollow structure. Figure 15.2 shows the size of raw and baked gluten balls, which indicates the relative amount of gluten in the various types of flour. Of course, some flours contain *no* gluten forming proteins. In that case, there is no gummy material created or retained!

Gluten in a dried form may be added to other flours, providing extra strength and several times the gluten-forming potential of that flour. Extracted gluten is

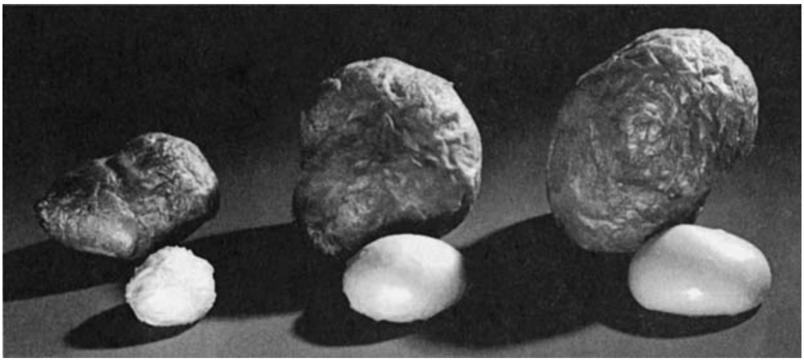

FIGURE 15.2 Unbaked and baked gluten balls. *Left to right:* Gluten balls prepared from cake flour, all-purpose flour and bread flour (*Source:* Wheat Flour Institute).

used to fortify protein content of some breakfast cereal, for binding breading on meat, poultry, or fish and as an extender for fish and meat products. As well, nonfood uses of gluten may be as a constituent of mascara and pharmaceutical tablets.

A look at the Codex Standard for gluten-free food, daily gliadin consumption and studies on the safety of wheat starch-based gluten-free foods are found in other literature (2)–(4).

FUNCTION OF VARIOUS INGREDIENTS IN BATTERS AND DOUGH

Not intended to be redundant (see Chapter 6) or even be a complete list, the following discussion will view the principle items that *might* be included in the preparation of batter and dough—flour, liquid, leavening, eggs, fat, salt, and sugar. Certainly baked products do not necessarily need all of these ingredients. The watery mixture of substances that they create bakes *around gas cells*, and subsequently determines texture, flavor, and appearance of baked products.

Flour Function

Flour provides structure to baked goods because of its *protein* and to a lesser degree its *starch* components. For example, to the extent that the *gluten-forming proteins* are present in flours, there is dough elasticity and structure (see Gluten) due to formation of a gluten matrix. *Starch* contributes structure to a batter or dough as it gelatinizes and makes the *crumb more rigid*. Additionally, flour is a source of fermentable sugar that is acted upon by yeast in producing CO_2 for leavening. Many types of flour (Chapter 6) are used in the preparation of baked goods.

Wheat flour is derived from the endosperm of *milled* wheat and is the most common flour used in the preparation of baked goods in the United States.

Specifically, ***all-purpose flour*** is chosen for use. It is produced by blending *hard and soft* wheat during milling and has applications in many baked products. Consumers refer to it simply as "flour."

- *Hard* wheat flour, such as bread flour has *high* gluten potential important for structure and expansion of yeast dough. It absorbs *more water* than an equal amount of soft wheat flour.
- *Soft* wheat flour, such as cake flour, contains *less* gluten forming proteins and is effectively used in the preparation of the more tender (due to less gluten) cakes and pastries. An equal amount absorbs *less water* than hard wheat flour (not an even exchange of flour type).

CULINARY ALERT! All "flour" used in a recipe is not created equal. High-protein "hard" flour absorbs more water that low protein "soft" flour, and thus flour cannot be interchanged in all cases. A recipe must specify and use flour accordingly to ensure product "sucess".

Whole-wheat flour differs from *wheat* flour, as it contains *all* of the three kernel parts, including the endosperm, germ, and bran (Chapter 6). *Bran* has sharp edges that *cut* through the developing protein structure and results in a *lower*-volume baked product, especially when a recipe replaces all of the flour with *whole-wheat* flour. Better results are seen when the flour is *finely ground* whole-wheat flour because it introduces *less* sharp edges, and therefore products exhibit *less* of a volume and texture difference. Due to the presence of *bran*, the percentage of protein is lower in whole-wheat flour than refined flour. Whole-wheat flour also contains the germ that may cause rancidity over time. Baked products may not remain uneaten for too long though.

CULINARY ALERT! Generally, when a whole grain flour is desired in a baked product, the recipe may replace the flour with no more than half whole grain flour, used in combination with half bread flour.

Although wheat flours are the most common types of flour used in baked products, *nonwheat* flours such as corn, rice, and soy also are popular in bread and the formulation combines the flour with wheat flour for more desirable baking results.

Regardless of the type of flour, it is typically *sifted* prior to measurement, as sifting standardizes the amount of flour added to a formulation and assures consistency in product preparation. Consistency *also* is more likely when ingredients are *weighed*, not measured.

Flour shows variance in the same brand of flour milled in *different milling locations* throughout the country. Due to these differences the same recipe may yield a slightly different finished product in different locations.

CULINARY ALERT! Adhere to appropriate measuring/weighing techniques, standardized recipes, and flour type for success when cooking/baking or in various parts of the country or world.

Liquids Function

Liquids are necessary to hydrate both *proteins* required for *gluten* formation and *starch* that undergoes gelatinization. These two form the texture of the baked crumb. Additionally, liquids are the solvent for dissolving many recipe ingredients such as the leavening agents baking powder and baking soda, as well as salt and sugar. Liquids produce steam that leavens and expands air cells during baking.

According to federal regulations, the water level of a finished commercially prepared bread loaf may not exceed 38%. *Liquids*, though, may contribute *more* than water. For example, while *milk* contains a very high percentage of water, it also *contains protein, milk salts*, and the *milk sugar, lactose*. Juices, sugar syrups, eggs, and so forth also may be part of the liquid in a recipe.

In general, its lactose milk produces a softer crumb, holds moisture in the product, and contributes both flavor and color from the Maillard browning. The *near-neutral pH* of milk causes it to act as a buffer, preventing an acid environment that would be unacceptable to the growth of bakers yeast.

The practice of *scalding* milk is thought to be *un*necessary. However, milk that is *not* scalded may contain whey protein that results in *diminished volume and poor quality*. This negative effect is especially true with the use of reconstituted, scalded nonfat milk solids (NFMS.) *Unreconstituted* NFMS powder also may be added to recipes to increase *nutritive value*.

Leavening Agents Function

Leavening agents are presented in more detail in a later section of this chapter. Overall, leavening agents raise dough or "make light and porous." They include *air, carbon dioxide* (CO_2), and *steam* discussed below. Virtually, all baked products are leavened to some extent, if not solely, by *air*. The amount of air depends on the mixing method, sifting flour prior to addition, beating, or creaming, and so forth. Consequently, there may be great variance in the *amount of air* that is incorporated into a batter or dough mixture.

Carbon dioxide gas is a leavening agent produced *chemically* by baking soda, and baking powder. It is produced *biologically* by yeast. These agents fill existing air cells and the gluten structures that then expand with the CO_2 they produce.

A third leavening agent is steam. *Steam* works in combination to further expand cell size, making batters and dough light and porous. Leavening agents make foam out of batters as they fill air pockets or cells, contributing to the "***grain***" of the product. Holes in the crumb may be large or small; they may be intact or exploded.

Egg Function

Eggs function in various manners in the batter or dough. They are *binders*, holding ingredients together. The *whole eggs* and *yolks* contain emulsifiers that distribute fat in the batter (a greater percentage of egg is necessary in a high-fat formulation compared to a low-fat or high-liquid formulation). Eggs leaven, provide coagulated structure, nutritive value, color, flavor, and more.

Whites contribute aeration and *leavening* when beaten due to the presence of air cells that are filled with CO_2 or expanded by steam. Egg whites produce a lighter, drier finished product. Eggs contribute elasticity to products such as popovers and cream puffs, thus when *omitted* from a formulation, the baked product is significantly (and unacceptably) lower in volume.

Structure provided by *flour* proteins forming a gluten matrix has been discussed previously. *Egg* proteins contribute to the structure as well, as they *coagulate* by heat, beating, or a change in pH. *Egg whites* incorporate air, but also may play an important part in *nutrition* as they function as a substitute for a portion of the whole egg in a formulation, thus reducing cholesterol levels.

The color and flavor imparted by eggs is especially significant in specialty ethnic and holiday breads and cookies. (More information on eggs is contained in Chapter 10.)

CULINARY ALERT! *Large* size eggs generally are used in a formulation that requires the addition of eggs.

Fat Function

Fats and oils are discussed in Chapter 12, and the reader is referred to that chapter for more specific information. Fat functions in *various* ways in batters and dough as is seen in Table 15.2 that illustrates effects of fats and oils on baked products. Fats and oils *tenderize* baked products by *coating* flour proteins in the batter or dough and physically interfering with the development of the gluten protein. They "*shorten*" by controlling gluten strand length; they create the *flakes* or *dough layers* seen in biscuits or pie crust. Fats *leaven* by incorporating air (creaming solid fats with sugar.) Fats and oils help *prevent the staling* process of baked products.

"***Plastic***" fats, such as hydrogenated shortening or some other solid fats may be spread or perhaps molded to shape; they do not pour. Hydrogenated vegetable shortenings and lard may contain emulsifiers (monoglycerides or diglycerides). These emulsifiers increase fat distribution and promote greater volume of the developed protein matrix, allowing it to stretch more easily without breaking.

Polyunsaturated oils yield a more ***tender***, mealy and crumbly product than *saturated* fats. This is because the oil covers a larger surface area of flour particles than *saturated* fat and it helps control/limit absorption of water (Chapter 12). Saturated fat, such as lard, cover less and produce a less tender, but *flaky* piecrust

TABLE 15.2 Effects of Fats and Oils on Baked Products

Coating and mechanical tenderizing effect—Fats and oils shield gluten protein from water, thus physically interfering with the hydration needed for gluten development. Both fats and oils tenderize baked products by coating, although oil (liquid at room temperature) coats more completely and yields a more tender product than solid fats; if coating is extreme, the texture of the product will be mealy and the dough will show reduced gluten formation.

Fats containing emulsifiers help water and fat to mix and may promote the stretching of gluten strands, yielding a higher volume of the baked product.

Shortening—Fats and oils minimize the length of developing gluten protein platelets; that is, they keep them short.

Flakiness—Plastic fat that is cut into pea-sized chunks in piecrust doughs (or smaller in biscuits) contributes the characteristic of flakiness to baked products as it melts in the dough, forming layers in the dough. Fats contribute *flakiness*; oil provides *tenderness*.

Leavening—Plastic fats may be creamed in order to incorporate air and aerate batters and doughs.

Less staling—Fats with monoglyceride addition, such as hydrogenated shortenings and commercially available lard, soften the crumb and function to retain moisture. It is primarily the amylopectin component of starch that forms a dry crumb.

with many layers in the dough. As discussed in Chapter 12, these two attributes cannot exist together.

Of course, when milk, especially whole milk, is used in a recipe, it contains *more* fat than juices or water and a *more* tender product is created. *Chilled* oils or fats exhibit slightly more flakiness in the baked product compared to room-temperature versions, as the *covering potential* is reduced.

CULINARY ALERT! In order to reduce saturated fat intake and for culinary success, *well-chilled* oils may be utilized instead of solid fats or even room-temperature oils.

Cup for cup, the various fats and oils *cannot* be substituted for one another and produce the same quality of baked product.

- Oils, hydrogenated vegetable oils, or animal fat (such as lard) are *100%* fat.
- Margarine and butter contain approximately 20% water.
- Reduced-fat "spreads" have an even *higher* percentage of water than margarine.

Fats containing water in the mix are *less* effective in their shortening ability than 100% fats. Often, specially modified recipes are required to assure success in baking with reduced-fat replacements.

Baked products such as angel food cake do *not* contain added fat in the formulation, whereas other products such as shortened cake and pastries are high in fat content. With a low-fat modification, products may be missing some of the flavor, tenderness, or flakiness that fat provided in the original version.

CULINARY ALERT! As appropriate, 1 cup of margarine or butter may be substituted with 7/8 cup of oil.

Salt Function

Salt is a *necessary* component of yeast breads because it dehydrates yeast cells and controls the growth of yeast with its CO_2 production. In a typical yeast dough the salt exerts an *osmotic effect*, competing with other substances for water absorption. Specifically there is *less* water for gluten development and *less* for starch gelatinization in salted yeast dough compared to unsalted dough. Salt contributes *flavor* to baked products.

The *absence* of salt in yeast bread dough allows rapid yeast development and rapid rising. This produces a collapsible, extremely porous structure, as gluten is overstretched and strands break.

CULINARY ALERT! Salt is a necessary component of yeast breads to control overproduction of yeast, and susequent dough collapse.

Sugar Function

In addition to contributing flavor, sugar functions in many additional ways in batters and dough. The presence of sugar makes a product tender. This is because as the sugar in a recipe *competitively absorbs water* (instead of flour proteins and starch), there is less water available for gluten formation and less for starch gelatinization. Sugar also *elevates the temperature* at which the protein coagulates and starch gelatinizes, thus extending the time for CO_2 to expand the baking dough.

Sugar is a *substrate for the yeast* organism, producing CO_2, acids, alcohols, and a number of other compounds.. Granulated white sugar, brown sugar, corn syrup, honey, and molasses are substrates for yeast, whereas artificial sweeteners cannot be fermented. Sugar exhibits *hygroscopic* (water-retaining) tendencies. Therefore, baked products may become overly moist, gummy, or runny, especially if the formulation is high in fructose (ie, honey). Reducing sugars, such as the lactose in milk, provide browning due to the Maillard browning reaction and sugars also caramelize.

The amount of sugar usage varies. A *small* amount of sugar is helpful to include in yeast bread formulations because it is fermented by yeast to produce CO_2. A *large* amount (more than 10% by weight) *dehydrates* yeast cells and *reduces* dough volume. Thus, a sweetened dough requires more kneading and rising time due to this osmotic effect of sugar. High levels of sugar are more easily tolerated in breads and cakes leavened by *baking soda or baking powder* than by yeast, since *yeast* cells are dehydrated by sugar. (As shown later, there may be occasions for using both leavens.)

Other types of sweeteners include the following:

- Honey may be used in baked products. It imparts varied flavors. When honey is used as a baking ingredient, it makes a sweeter and moister baked product because it contains fructose, which is sweeter and more hygroscopic than sucrose.
- *Molasses* imparts its own characteristic flavor which may be very strong. It may be used as the sweetener in baked products, yet because it is more acidic than sugar it should *not* be used to replace more than half of the total amount of sugar in a recipe. In order to control acidity, it may be necessary to add a small quantity of baking soda. As is the case with honey, when molasses is substituted for sugar, there needs to be a reduction in the amount of liquid in the recipe.
- *Sugar substitutes* provide sweetness but do not provide the functional properties of sugar, including browning, fermenting, tenderizing, and hygroscopic properties of sugars (see Chapter 14). Among sugar substitutes, an equal replacement of one sugar substitute for another, by weight, is not possible due to inherent differences in bulk and sweetness. *Acesulfame K, aspartame* (if encapsulated), and *saccharin* are examples of heat-stable sugar substitutes successfully incorporated to some degree into baked products (more in Chapter 14)

THE LEAVENING PROCESS OF BAKED PRODUCTS

Leavening of quick breads and yeast breads occurs when the air spaces or gluten structure are filled with a leavening agent. For example, after gluten has formed in dough and the dough has subsequently been fermented, the gluten structure becomes extensible for the leaven inside. As previously discussed, leavening agents include air, steam, or CO_2, which become incorporated into the structure. The latter is produced either biologically or chemically. As dough is *proofed*, or rises in its final rising (usually yeast dough is raised two times), the gluten structure expands, dough increases in volume and makes a product light and porous.

Air as a Leavening Agent

Air, which is incorporated to some extent into *almost every* batter and dough, expands upon heating and increases the volume of the product. It may be the only leavening agent in "unleavened" baked products such as some breads, crackers, or piecrusts. Air may be incorporated by *creaming* fat and sugar for a cake, by *beating* egg whites/whole eggs for angel food or sponge cake by sifting ingredients or by *folding* (lifting and turning) the airy egg into the mixture. After its introduction into the food, air cells expand with heat in baking and another leaven, such as steam or CO_2, diffuses into the air space, enlarging it.

Steam as a Leaven

Steam too, partially leavens *almost everything*. One part of water creates 1600 parts of steam vapor. Steam is produced from liquid ingredients, including water, juices, milk, or eggs. Products such as cream puffs or popovers are dependent on steam formation for leavening and a hollow interior. They obtain their characteristic high volume and hollow interior as dough protein expands due to steam development and as the egg protein denatures and coagulates. A *high* liquid-to-flour ratio and a *high* oven temperature are needed for water vaporization and dough expansion in products leavened mainly by steam.

Carbon Dioxide as a Leaven

Carbon dioxide is a *major* leavening agent in batters and dough. The amount required in a formulation is proportional to the amount of flour. For example, a formulation that is high in flour (dough) requires more CO_2 production for leavening than does a high-liquid (batter) product; therefore, the recipe must contain *more* of the ingredient responsible for forming CO_2.

Chemical Production of CO_2

CO_2 may be produced *chemically* (5, 6) by the reaction of sodium bicarbonate with an acid (wet or dry), or it may be produced *biologically*, through bacteria or yeast fermenting sugar (7). CO_2 is easily *released* into a batter and it may also easily escape, becoming unavailable for leavening. This occurs if a batter or dough is left unbaked for an extended time period or if the gluten structure is not sufficiently developed to allow extension with the CO_2.

Baking soda. One means of chemical leavening is by *baking soda*, or sodium bicarbonate. It chemically produces CO_2 as follows:

Na_2CO_3	+	heat → Na_2CO_3	+	CO_2	+	H_2O
Sodiumbicarbonate		Sodiumbicarbonate		Carbondioxide		Water

When used *alone*, baking soda reacts *quickly* with heat and CO_2. It may *escape* from the raw batter before it is able to leaven. Therefore, baking soda must be *combined* with another substance to make is useful. The choices are either (1) *liquid acid*, or (2) dry acid, plus liquid, in order to *delay* production of CO_2 and prevent escape from the mixture. Examples are below:

- Liquid acids: applesauce, buttermilk, citrus juices, honey, molasses, and vinegar.
- Dry acid: cream of tartar (potassium acid tartrate, a weak acid), shown below:

$HKC_4H_4O_6$	+	$NaHCO_3$	→	$NaKC_4H_4O_6$	+	CO_2	+	H_2O
Cream of tartar		Sodium bicarbonate		Sodium potassium tartrate		Carbon dioxide		Water

If a batter or dough is made *too alkaline* with the addition of baking soda, sodium carbonate is produced in the food product and it forms a *soapy flavor, spotty brown color, and yellowing* of the flavonoid pigment. This may occur in buttermilk (soda—acid) biscuits if soda is present in greater amounts than the acid with which it reacts. Soda–acid biscuits exhibit *more* tenderness than baking powder biscuits because the *soda* softens the gluten.

In contrast to alkalinity, the pH may be *too acidic*. If it is too acidic, baked products such as biscuits exhibit whitening in color.

CULINARY ALERT!

- Baking soda is added to the recipe ingredient mixture along with the *dry* ingredients. If it is added with the *liquid* ingredients, CO_2 may be prematurely released into the liquid and escape from the mixture during manipulation.
- Baking soda may be used to neutralize mildly acidic juice

Baking powder. A *second* means of supplying CO_2 gas *chemically* is via the use of baking *powder*. It was first produced in the United States in the early 1850s and quickly provided consumers with the convenience of a premixed leaven. Baking powder contains three substances: sodium bicarbonate (baking soda), a dry acid, and inert cornstarch filler. The starch filler keeps the soda and acid from reacting with each other prematurely and standardizes the weight in the baking powder canister. Commercial baking powder must yield at least 12% available CO_2 gas by weight (each 100 g of baking powder must yield 12 g of CO_2), and home-use powders yield 14% CO_2.

Baking powders are classified in several manners. One method is according to the *type of acid* component. The acids differ in strength, and thus each determines the rate of CO_2 release. While in the past, tartrate and phosphate were used as the dry acid, now consumers use the more common *SAS* phosphate (sodium aluminum sulfate phosphate).

Baking powders also are classified according to their *action rate* or how quickly they react with water and heat to form CO_2. A *fast-acting* baking powder, such as the monocalcium phosphate, is a *single-acting* powder whose soluble acids release CO_2 almost *immediately* upon moistening/mixing with liquid at room temperature. The SAS phosphate is slow-acting, and a *double-acting* powder that releases CO_2 *two* times. The first release of CO_2 occurs as the mixture is *moistened*; the second occurs as the mixture is *heated*.

If an *excessive* quantity of baking powder is added to a formulation, cell walls may be stretched and break. This breakage results in a coarse textured, low-volume product, due to an overstretched, collapsed structure and release of CO_2

bubbles. The use of excessive baking powder also results in a *soapy* flavor, *yellow* crumb, and overly *browned* exterior.

Inversely, if *too little* baking powder is used, the product is *not* sufficiently leavened. The finished baked product is soggy with a compact grain of small air cells in the batter or dough.

Cracks may form in some SAS phosphate baking powder used in biscuits because of attempted leavening with insufficient dough stretching. This might be due to inadequate manipulation of dough required for gluten development.

A distinction between the use of baking *soda* and baking *powder* is seen when *baking* various biscuits. For example:

- *Baking soda* + buttermilk (liquid acid) for buttermilk biscuits (baking soda requires an acid).
- *Baking powder* for baking powder biscuits.

The occasional inclusion of *both* baking powder and baking soda may be necessary if the amount of soda and liquid acid would not amply supply the CO_2 that is needed to leaven the mixture

CULINARY ALERT! If baking powder is not available for use, substitution may be made. One teaspoon of baking powder is replaced by 1/4 teaspoon baking soda and ½ teaspoon of cream of tartar.

Biological Production of CO_2

Leavening may occur by the above-mentioned nonfermentation methods, using air, steam, or chemical CO_2 production. Leavening may be the result of ***fermentation***, the *biological* process in which the microorganisms *bacteria or yeast*, function to metabolize fermentable organic substances.

Bacteria. An example is *Lactobacillus sanfrancisco*. This is the bacteria responsible (along with a nonbakers' yeast *Saccharomyces exiguus*) for forming sourdough bread. The bacteria function to degrade maltose, yielding acetic and lactic acid and producing CO_2. It is common that *starters* or *sponges* of dough containing the bacteria, along with yeast, may be saved from one baking and used in a subsequent baking (see below).

CULINARY ALERT! Commonly shared among friends in their home kitchens, a "starter" culture or "sponge" may be used in bread-making. The starter is retained from a previous bread making, and reused, therefore fresh yeast is not required each time bread is prepared.

Yeast. The most common strain of yeast used in bread making is *Saccharomyces cerevisiae*. It is a microscopic, one-celled fungi, a plant without stems or chlorophyll that grows by a process known as budding—a new cell grows and comes from an existing cell. It releases zymase, which metabolizes *fermentable sugars* in an anaerobic process, yielding ethanol and CO_2 (with more yeast cells,

TABLE 15.3 Forms of Yeast

- **Active dry yeast** (ADY)
  - 1 teaspoon ADY = 1 cake of compressed yeast (CY)
  - Contains approximately 2–1/4 teaspoons per envelope
  - Leavens 6–8 cups of flour
  - Has a longer shelf life than CY
  - Less moisture than CY
- **Cake or compressed yeast** (CY)
  - Moist yeast with starch filler
  - Short shelf life—must be refrigerated or yeast cells die
- *Quick* **rising dry yeast**
  - Is rapidly rehydrated
  - Raises a mixture rapidly
  - Is formed by protoplast fusion of cells

more CO_2 is produced.) Most of the alcohol is then volatized in baking and the CO_2 provides leavening. The three main forms of yeast used in food include those listed in Table 15.3.

Yeast is a fungus that leavens. It is developed by warm water and fed by the substrate sugar, fermenting it to yield carbon dioxide. In the presence of liquid and temperatures of 105–115°F (41–46°C), each yeast cell rehydrates and *buds*, producing new cells (see below). Reaching temperatures *greater than* 130°F (54°C) has a negative effect (thermal death) on yeast development, and *colder temperatures* are ineffective.

Due to the osmotic pressure that sugar exerts, more time is necessary to leaven *sweetened* yeast dough. It is possible that leavening may utilize baking soda or baking powder (chemical leavens) along *with* the yeast (biological leaven), especially if the recipe uses a high level of sugar that inhibits gluten development and the subsequent rise. Either may be added to the dough at the second rise to provide extra leavening.

CULINARY ALERT! Directions for using the more recently developed "quick-rise yeast" may differ from what the experienced bread maker has learned about how to use yeast. Best advice: read the label!

There is a noticeable effect of spices on yeast activity. Spices such as cardamom, cinnamon, ginger, and nutmeg greatly *increase* yeast activity, as does the more savory addition of thyme. The use of dry mustard has the opposite effect and *decreases* yeast activity.

CULINARY ALERT! Think of the festive and holiday breads you create and the effect of the added spice.

FIGURE 15.3 Yeast-leavened wheat breads (*Source*: Wheat Foods Council).

INGREDIENTS IN SPECIFIC BAKED PRODUCTS

Through an application of previously presented *general* concepts, the role of ingredients in some *specific* baked products will be examined.

Yeast Bread Ingredients

Yeast breads (Figure 15.3) are prepared from *soft dough* (1:3 to 1:4 ratio of liquid to flour) using *hard wheat* flours to form a gluten structure that is strong and elastic. The structure may contain starch and sugar or other ingredients such as eggs and fat. The yeast is responsible for the production of CO_2 within the gluten structure, and in turn the CO_2 is responsible for the reduction of pH from 6.0 to 5.0.

Four mandatory yeast bread ingredients in the United States are *flour, liquid, yeast, and salt*. Additionally, sugar and the commercial enzyme α-amylase may be added during the commercial preparation of bread loaves.

(The enzyme is naturally present in flour and may cause *unwanted* hydrolysis of the starch; however, it may be added in order to form *desirable* structure and texture in bread making and in creating food for yeast. Starch hydrolyzing enzymes in flour such as *amylase* are important dough ingredients in commercial bread making because they produce such fermentable sugars upon which yeast acts. [*α-Amylase* breaks off one glucose unit at a time immediately yielding glucose, and *β-amylase* breaks off two glucose units, yielding maltose.])

Yeast will be addressed later in this chapter, however, the following are yeast bread ingredients.

Flour. Yeast breads are made with *hard flour*. Adequate gluten development and viscoelasticity are required for the entrapment of the CO_2 evolved from yeast fermentation. Some flours are *not* suitable for bread making, as they do not have gluten potential. Isolated gluten also may be added to flour to yield high-gluten flour. The *starch* component of flour also contributes to structure as it is gelatinized. In part it is converted to sugar, which provides food for yeast.

Liquid. Liquid is necessary to hydrate flour proteins, starch, and yeast cells. Milk or water, warmed to approximately 105–115°F (41–46°C) allows yeast cells to begin development (to bud). Higher or lower temperatures do not activate yeast or may destroy it.

Salt. Salt is a *required* ingredient in yeast formulas. It is added for flavor and to control gluten development, so that the gluten stretches sufficiently yet not too much, causing breaking. If salt is omitted from a formulation, a collapsible structure would result from weak, overstretched gluten.

Sugar. The initial incorporation of a *small* amount of sugar with yeast promotes yeast growth. Sugar also functions to brown the crust of yeast breads by the Maillard browning reaction and it tenderizes dough if added in large amounts. *High* amounts of sugar *inhibit* yeast development. With *high* amounts of sugar, *less salt or more yeast* may be added.

Optional Ingredients Used in Yeast Breads. Optional ingredients in yeast bread making are *many*, determined in part by cultural or family preference. Yeast breads may include sugar, fat and *eggs*. Fat may be added for flavor and tenderness; eggs may be added to provide emulsification, for nutritive value, flavor, or color. The incorporation of various *spices*, including ginger, cinnamon, cardamom, and thyme, increase gas production in dough by chemically enhancing yeast fermentation. The addition of dry mustard exhibits an inhibitory effect on yeast development (8).

CULINARY ALERT! Many other ingredients from A–Z are added to batters and dough. This assortment includes apples, carrots, cheese, dried beans, citrus fruit zest, dill, herbs, nuts, olives, sun-dried tomatoes, and zucchini, to name a few!

Quick Bread Ingredients

Quick breads, as their name implies, are relatively *quick* to mix before baking, and are baked immediately without the lengthy waiting period as required of yeast breads. The leaven typically is *chemically* produced by baking powder, baking soda, or by steam and/or air, and is *not biologically* created. Quick breads include the biscuits, loaf breads, muffins, pancakes, popovers, and waffles among the variety of other baked products represented in Figure 15.4.

Flour. *All-purpose flour* is used to provide an adequate gluten structure for quick breads. The high liquid to flour proportion in a quick bread formulation limits gluten development and yields a tender product. Too much flour may produce excessive gluten, tunnels, and a dry crumb.

Liquid. Water, juice, or milk may be used as the dispersing medium for sugar, salt, and the leavening agent. As the liquid is heated, it forms steam, which leavens, gelatinizes starch, and contributes rigidity to the crumb.

Eggs. Eggs provide *structure* as they coagulate. They emulsify quick bread batters, allowing the *lipid* part to combine with *liquid* due to the presence of phospholipids in the yolk. Eggs also impart nutritive value and color.

Fat. Various fats and oils are used in quick bread production. *High* levels of fat limit the development of gluten. *Oil* coat flour granules, *covering* them to prevent water absorption. For example, oil is used in pancakes and muffins and pea-sized chunks of solid fat are used in the preparation of biscuits to form flakes.

When formulations are modified for health purposes, such as may occur with the substitution of *oil for fat*, there is a noticeable change of quality. For example, the absence of flakes in biscuits becomes apparent. When a formulation is reduced-fat or fat-free, it produces a *less* tender crumb due to the *increased* development of gluten.

Leaven. Typically, quick breads are chemically leavened quickly. Baking powder, eg, baking powder biscuits, or baking soda and a liquid acid, eg, buttermilk biscuits (A substitution: 2 tsp. baking powder + 1 cup milk = 1/2 tsp. soda + 1 cup buttermilk.)

Sugar. Sugar provides sweetness and tenderization. It also assists in the Maillard browning reaction. *High* levels inhibit gluten development.

Pastry Ingredients

Pastry may exist in several forms. Depending on the specific product desired, the quantity and type of fat/oil, flour, liquid, and so forth, will vary. Piecrust is made from a *high-fat* stiff dough that has one of two distinct features, either *tenderness and flakiness*. Pastries also may be made from layered puff pastry dough or from a thick paste such as *choux paste*, for cream puffs and éclairs. These latter two forms of pastry dough may rise to several times the raw dough size when baked. The function of various ingredients in pastry is identified in the following subsections.

Flour. Pastry flour is best to use because it *is soft wheat flour* that is low in protein. If unavailable, it may be created using a blend of *hard and instantized flour*. Pastry flour or the blend of flour produces *less* gluten than either all-purpose and hard wheat flour, and yields a *more tender* product.

CULINARY ALERT! If all-purpose or hard flour is used when the recipe specifies pastry flour, recall that hard flour absorbs more water, and therefore less of it must be used than soft types to yield the same consistency.

Liquid. The liquid in pastry dough is chiefly water. Water hydrates flour, promotes gelatinization, and forms cohesiveness. A pastry may depend on steam from an egg to leaven. As the liquid of egg changes to steam, it leavens the mixture, ie, cream puffs, and it contributes a gel-like interior to the hollow wall.

(Although not made from a thick paste or high fat pastry, another hollow baked product is the popover, a quick bread made from a high liquid pour batter.)

Fat. Solid pea-sized chunks of *fat* in pastries melt to form many *flaky* layers in a crust, such as a piecrust. The use of *oil* in a recipe coats flour particles and permits *less* hydration of the flour. With the use of oil, piecrusts will exhibit a crumbly, mealy nature and produce a pastry crust that is *not flaky, but tender*.

Lard and *hydrogenated shortenings* are solid shortenings that produce *very flaky* pastries, while *butter* and *margarine* are solid at room temperature but contain 80% fat and 20% liquid, thus *reducing* flakiness. Reduced fat and fat-free margarines do not contain sufficient levels of fat to function well in pastry. Pastries that are typically high in fat will not be as tender if the recipe is subject to fat reduction (Chapter 12).

Other Pie Pastry Ingredients. A piecrust may contain other ingredients depending on the pie type. For example, *savory* crusts for a quiche may contain cheese or herbs. *Sweet* dessert crust may contain other spices, chocolate, or sugar for color or flavor. If made with sugar, crusts easily brown.

Cake Ingredients

Cakes commonly contain ***fat*** and ***sugar***. Obviously there are many types and varieties of cake! However, this discussion is applicable to typical layer cakes. Many of the ingredients affect the cake volume and texture. Some functions of cake ingredients are presented in the following subsections.

Flour. *Soft* wheat (7–8.5% protein) cake flour is desirable for cakes. The soft flour particles are small in size and the cake is more lofty and tender with a finer grain than hard flour with its higher gluten-forming ability. Thinner walls, increased volume, and a less coarse cake result from using soft cake flour.

If the flour is *bleached*, as is often the case with cake flour, there are two advantages: (1) the pigment is whiter, and (2) the baking performance is improved because, among other characteristics, bleaching oxidizes, the surfaces of the flour grains, higher loaf volume and finer grain result.

CULINARY ALERT! At the household level, 1 cup of all-purpose flour minus 2 tablespoons is used to replace 1 cup of cake flour in a formulation.

Liquid. Liquid gelatinizes starch and develops *minimal* gluten. *Fluid* milk hydrates protein and starch providing structure and crumb texture. The milk sugar, lactose, and protein are valuable in determining the color of a finished cake. Milk proteins combine with sugars in nonenzymatic, Maillard browning.

Eggs. The protein of whole eggs or egg whites provides *structure* and may toughen the mixture as the protein coagulates. Egg *whites* leaven because they are beaten to incorporate air and they provide liquid, which leavens as it becomes steam. *Sponge cakes* incorporate whole egg and *angel food cakes* are prepared with beaten egg whites to create volume. Egg yolks, due to their lipoprotein content, function as emulsifiers. The addition of extra fat and sugar offset the toughness of egg in a formulation.

Fat. Fat functions in tenderizing cakes, since it shortens protein–starch strands. It provides increased volume, especially if creamed in a recipe or if monoglycerides and diglycerides are used as emulsifiers in the fat. *Butter* in a formulation may require more creaming than hydrogenated shortening because it is not as aerated and it has a narrow plastic range (Chapter 12). *Lard* has a large crystal size, and therefore creams less well than most plastic fats. *Oils* produce tenderization. Fat in a recipe also functions to retain moisture in the mixture and it softens the crumb. Shortened cakes differ from sponge cakes in that the latter have no fat beside egg.

CULINARY ALERT! Extra fat in the form of sour cream or eggs provides tenderness and flavor.

Sugar. Sugar imparts a sweet flavor to cakes and often is added to cake batters in large amounts. It competes with the protein and starch for water and inhibits both *gluten development and starch gelatinization*. Sugar also functions to incorporate air when plastic fats are creamed with sugar prior to inclusion in a batter. Even if not creamed, its addition increases the number of air cells in the batter, contributing to the *tenderness* of the grain.

Leaven. Leavening is created in several ways. The grain shows evidence of numerous air cells that hold expanding gases released by the leaven. The process of creaming fat and sugar incorporates air to leaven. Baking soda reacts with an acid ingredient to leaven. The use of chemical leavening by both baking soda and baking powder is common, as is steam and air.

MIXING METHODS FOR VARIOUS BATTERS AND DOUGHS

The *function* of batter and dough *ingredients* and ingredients in specific baked products have been addressed in former sections. This section covers *specific mixing methods* for various batters and dough. The function of *mixing* is to distribute ingredients, including leavening agents, and to equalize the temperature throughout a mixture. *Dough* such as that in biscuits and pastries are manipulated by *kneading*; cakes, muffins, and pour *batters* are *stirred*.

CULINARY ALERT! Depending on the mixing method utilized, two baked products with the exact same ingredients and proportions may yield two different end results! Due to various mixing methods, volume, texture, and grain size may differ.

Biscuits

Biscuits are quick breads made of *soft* dough. The recommended mixing method is to cut a *solid fat*, pea size or smaller, into the sifted, dry mixture. Next, *all* of the liquid is added, a ball is formed and the dough is kneaded. Kneading (see Yeast Dough, Kneading) 10–20 times develops gluten and orients the direction of gluten strands, necessary to create flakes. It mixes all ingredients, such as the *baking powder or soda* and *acid*, which leaven. *Under*kneading produces a biscuit that fails to rise sufficiently.

*Over*kneading or rerolling overproduces gluten and results in a smaller-volume, *tougher* biscuit, which will not rise evenly because CO_2 escapes through a weak location in the gluten structure.

Cakes

Cake batters may be prepared by several different methods. *Conventionally*, they are mixed by first creaming a plastic fat with sugar, which provides aeration of the cake batter. Next, the egg is added and the dry and wet ingredients are added alternately. A second method, or "*dump*" method, mixes all of the items and then adds the leaven at the end.

CULINARY ALERT! With a lack of creaming, loftiness is sacrificed because the number of air cells that can be filled with CO_2 is reduced.

Muffins

Muffins are a quick bread prepared from *drop* batter. The optimal mixing method for muffins is to pour *all* of the liquid ingredients into all of the sifted, dry ingredients and *mix minimally*. Overmixing a high-gluten-potential batter develops long strands of gluten and results in the formation of tunnels or peaks in the muffin (see below).

Tunnels, or hollow internal pathways, form long strands of gluten, allowing gases to escape from the interior. Muffins also may take on a peaked appearance if the oven temperature is too high, allowing a top crust to form while the interior is still fluid and maximum expansion of the muffin has not occurred. A center tunnel forms for gases escape, creating a ***peak.***

Of particular interest are:

- *Bran muffins*: Pieces of the bran physically *cut through* the developing gluten strands during mixing, and thus bran muffins do not rise as much as non-bran-containing muffins.
- *Corn muffins*: Since corn, a nongluten flour is used in a formulation, it is best to mix it with an *equal* amount of wheat flour in order to obtain a desirable structure.

Pastries

The mixing method for pastry is similar to biscuit preparation. It involves cutting the large amount of solid fat into the sifted, dry ingredients, then adding all of the liquid. The mixture may be stirred, then kneaded, and cut to desired shape. Croissant pastry dough must be repeatedly *folded*, not stirred or kneaded, numerous times over the course of several hours. This folding produces layers in the dough. If oil is incorporated, well-chilled oil restricts the covering potential of room-temperature oil and produces a slightly flaky product.

Pour Batters

Items such as pancakes, popovers, and waffles contain a high proportion of liquid to flour and do *not* require a definite manner of mixing. Overmixing is *unlikely* to affect the shape or texture of the finished product due to the high level of water and low level of gluten development.

Dough, Yeast Dough

A discussion of yeast bread dough mixing is presented below. Preparation of yeast dough includes kneading, fermenting, punching down the dough, resting, shaping, and proofing dough.

Subsequent to combining all of the ingredients into a ball, *kneading* must occur to stretch and develop the elasticlike gluten. This is done by pressing dough down, folding it in half, and giving a half-turn to the dough in between each pressing and folding. ***Kneading*** incorporates and subdivides air cells, promotes evenness of temperatures throughout the dough [75–80°F (27°C)], removes the excess CO_2 (which may overstretch the gluten structure) and distributes the leavening agent.

Kneading may be accomplished utilizing a heavy-duty mixer, bread machine, or food processor, perhaps requiring 10, 5, and 1–2 minutes, respectively. *Under*kneading or use of nongluten-forming flour will produce less/no gluten strands, and thus breads with less volume. *Over*kneading also is possible, especially with the use of machine kneading. If this is the case, there may be a break of the gluten strands resulting in a less elastic mass of dough that fails to rise satisfactorily.

Following kneading, a yeast dough is left to rise as yeast cells undergo *fermentation* where fermentable sugar is converted into ethanol and CO_2. The dough has doubled in size when the rise is complete. Then, the dough is *punched down* (Figure 15.5). Punching down is beneficial in that it allows the heat of fermentation and CO_2 to escape, introduces more oxygen, controls the size of air cells, and prevents overstretching and collapse of gluten. If dough is allowed to rise *too much*, gluten is overstretched causing the dough to be inelastic and unextensible.

This punching down provides yeast contact with a fresh supply of food (the sugar) and oxygen. The dough is punched down and left to rest for 15–20, so that gluten strands *rest or relax*, and the starch absorbs water in the dough to make it less sticky. In this time period, fermentation continues and the gluten network becomes easier to manipulate.

Subsequent to the rest period where gluten is relaxed, the dough is *shaped* and allowed to rise a second time; it is ***proofed***. The dough will have *doubled* in volume in the second rise, as many more yeast cells have budded and produced additional CO_2. It is ready to bake when a slight indentation mark remains in the dough when it is pressed lightly with the fingers.

In any of the above procedures when the stretched gluten structure collapses, volume decreases due to CO_2 loss, and the texture thus is noticeably coarse, open, and dense instead of fine and even. In the case of overrisen dough, it should be punched down again and allowed to rise a third time, so that it is not baked in a condition where the overstretched structure will collapse.

CULINARY ALERT! Knead enough, however, not too much!

BAKING BATTERS AND DOUGHS

Unbaked batters and dough are foams of watery substance surrounding air cells. This surrounding mixture forms the *grain* of the finished product as it "sets" or coagulates around air cells. Major product changes that occur during baking involve protein, starch, gases, browning, and importantly, a release of aroma!

- *Proteins* in the flour or added protein ingredients harden or coagulate by heat.
- *Starch* granules lose their birefringence, swell, and gelatinize as they imbibe moisture.
- *Gases* expand and produce leavening.
- *Water* evaporates and a browning of the crust becomes evident due to the Maillard browning reaction.
- The *alcohol* by-product of yeast fermentation evaporates, albeit not completely.

The qualities of a finished baked product may be determined by the degree of manipulation (stirring, kneading) and oven temperature. The type of flour, the amount of liquid, and an almost unlimited list of possible added ingredients affect quality.

CULINARY ALERT! A split top seen in a rectangular-shaped baked cake is due to the setting of the structure on the outer surface while the interior is still fluid.

In the oven for a few minutes, yeast breads will exhibit an initial rising of the loaf known as "***oven spring***." Oven spring occurs with the volatilization of ethanol produced during fermentation. Then, the rise is due to expansion with heat, yeast's CO_2, and the steam from water. Gases expand the gluten strands until they form a rigid structure. However, *over* fermentation and *over*proofing result in the ballooning of the loaf of bread, followed by a likely collapse in structure, as previously discussed. Flavor develops as the crust browns with water loss and aroma is released.

Altitude-Adjusted Baking

As a reference, water boils at a *lower* temperature with higher elevation: a few °C or approximately 10°F less, 203°F (95°C) at 5000 feet, and 198°F (92° C) at 7500 feet. Therefore, foods cooked in water have to be cooked substantially longer to get them done. Even when water comes to a rapid boil, it is not as hot at high altitudes as rapidly boiling at sea level!. Baking requires an increase in time too. At lower altitudes water boils at a higher temperature and an increase in leaven is needed.

When a product is baked at *high* altitude, there is less atmospheric resistance and it takes longer to bake. The lowered air pressure also tends to cause the air bubbles in baked goods to rise faster, producing increased dough expansion. Then these air bubbles escape to the atmosphere causing the cake to fall. The inverse is true regarding low altitudes and high atmospheric pressure. Therefore, local instructions specific to the altitude must be followed in manufacturing, food service, or home recipes.

At high elevations (5000 ft or more above sea level), a *reduction in sugar* and *less leaven* is needed. A reduction in sugar provides *less* competition for the water, and therefore water is available to develop a strong gluten structure. Less leaven prevents the over-expansion of dough that so easily may occur with the lower atmospheric pressure.

”With less air pressure weighing them down, leavening agents tend to work too quickly at higher altitudes, so by the time the food is cooked, most of the gasses have escaped, producing a flat tire. For cakes leavened by egg whites, beat only to a soft-peak consistency to keep them from deflating as they bake. Also, decrease the amount of baking powder or soda in your recipes by 15% to 25% (one eighth to one quarter teaspoon per teaspoon specified in the recipe) at 5000 feet, and by 25% or more at 7000. For both cakes and cookies, raise the oven temperature by 20° or so to set the batter before the cells formed by the leavening gas expand too much, causing the cake or cookies to fall, and slightly shorten the cooking time.

“Flour tends to be drier at high elevation, so increase the amount of liquid in the recipe by 2 to 3 tablespoons for each cup called for at 5000 feet, and by 3 to 4 tablespoons at 7000 ft. Often you will want to decrease the amount of sugar in a recipe by 1 to 3 tablespoons for each cup of sugar called for in the recipe“ (9).

“There are some standard adjustments you can make. At 7000 ft., for each cup of liquid called for in the recipe, increase it by 3 to 4 tablespoons. For each teaspoon of baking powder called for, decrease the amount by 1/4 teaspoon. For each cup of sugar in the recipe, decrease the amount by 1 to 3 tablespoons.

“For cakes leavened by egg whites, beat only to a soft peak consistency to keep them from expanding too much as they bake. For both cakes and cookies, lower the oven temperature by 20 degrees or so and slightly shorten the cooking time. You will want to keep the changes on the small side the first time you prepare a recipe, and adjust as needed subsequently“(9).

STORAGE OF BAKED PRODUCTS

Proper storage of baked products extends shelf life and maintains the best flavor and texture. Covering and elimination of external air is a step normally taken to protect baked products, thus a good wrap or airtight storage is recommended. Such storage also may deter staleness. For long-term storage, use of a freezer wrap prior to freezer storage minimizes dryness or freezer burn.

NUTRITIVE VALUE OF BAKED PRODUCTS

The nutritive value of baked products varies according to the type and amount of ingredients used in the formulation. The primary ingredient of many baked products is flour. However, there may be a significant amount of fat or sugar. Generally, food choices that provide less sugar and fat in the diet should be selected, as fats and sweets should be used sparingly.

Whole grains, fruits, grated vegetables such as carrots, or zucchini, nuts, and NFMS, may be used in recipes providing appearance, texture, and flavor benefits, and boosting nutritive value. Individuals following a gluten-free dietary regimen may avoid specific flours such as wheat and instead choose flour such as rice flour to bake.

Reduced-Fat and No-Fat Baked Products

Some baked products may be prepared successfully with a reduction in the fat content, and this modification may fit into many fat- or calorie-restricted diets. However, the product will be *less* tender and flavorful than the unmodified original counterpart. The result of reducing or eliminating fat is altered flavor, more gluten development, and less tenderness than a product with the standard amount of fat.

CULINARY ALERT! Reduced and low-fat baked products may be desirable, however, such products may not result in quality that is acceptable to all individuals.

SAFETY ISSUES IN BATTERS AND DOUGHS

Microbial Hazards

"Rope" is a condition attributed to bacilli *bacteria* in flour. It may be present in the field from which a crop was obtained to produce flour. Its presence causes a syrupy ropelike interior of bread; it stretches and appears as a rope. An acid environment (pH 5 4.5) prevents this growth of bacteria.

Mold spoilage also is possible. Therefore, mold inhibitors such as *sodium or calcium propionate or sodium diacetate* commonly are added to commercially prepared bread to inhibit mold and bacteria.

Nonmicrobial Hazards

Nonmicrobial deterioration may occur due to rancidity or staling (Chapter 5). Both terms previously have been discussed in earlier chapters. A little about staling is justified here. Staling is defined as all those changes occurring after batters and dough are baked. It is thought that deterioration primarily involves recrystallization of amylopectin, and it includes a change in flavor, a harder, less elastic crumb, and less water-absorbing ability. In order to partially restore flavor, brief reheating is recommended. If heat is prolonged or too high, a dry crumb is evident. Foreign substances also pose hazards if found in foods. Controls must be established and enforced to protect against deterioration and hazards. (Chapter 16)

CONCLUSION

Batters and dough are made with different types and proportions of liquids, flour, and other ingredients such as leavening agents, fat, eggs, sugar, and salt. Depending on the amount of flour, batter may be a pour type or drop batter and dough may be soft or stiff. A formulation that includes wheat flour forms a protein network known as gluten and liquid gelatinizes starch as the batter or dough bakes. Both gluten and gelatinized starch contribute to the structure of baked products. A quick bread is quick to prepare, whereas yeast breads require more lengthy time periods for the yeast to raise bread prior to baking.

Sugar and salt contribute flavor and exert an osmotic effect on dough as they compete with other added substances for water absorption. A small amount of sugar serves as the substrate for yeast in fermentation, whereas a large amount of sugar interferes with CO_2 development by dehydrating yeast cells. Salt is needed for control of yeast growth.

Baked products may be leavened with air, steam, or CO_2 which enlarges air cells and raises dough. Carbon dioxide may be produced biologically by yeast or chemically by baking powder or baking soda. Leavening also is accomplished by air or steam.

Fat is considered optional in some batters and dough and mandatory in other baked products. Liquid oil coats flour particles more thoroughly than solid fat, limiting gluten development and contributing tenderness. Solid fat, cut into pea-sized chunks or less, melts forming layers in pie crusts and biscuits, respectively. Eggs may be added to batter and dough formulation.

Egg whites may be beaten to incorporate air; whole eggs or yolks contribute nutritive value, color, flavor, and emulsification. The nutritive value of baked products is dependent on the individual recipe ingredients.

GLOSSARY

All-purpose flour: The flour created by a blend of hard and soft wheat milling streams.

Batters: Thin flour mixtures that are beaten or stirred, with a 1:1 or 1:2 ratio of liquid to flour, for pour batters and drop batters, respectively.
Dough: Thick flour mixtures that are kneaded, with a 1:3 or 1:6–8 ratio of liquid to flour for soft and stiff dough, respectively.
Elastic: Flexible, stretchable gluten structure of dough.
Fermentation: A biological process where yeast or bacteria, as well as mold and enzymes, metabolize complex organic substances such as sucrose, glucose, fructose, or maltose into relatively simple substances; the anaerobic conversion of sugar to carbon dioxide and alcohol by yeast or bacteria.
Flaky: Thin, flat layers of dough formed in some dough such as biscuits or piecrusts; a property of some pastries that is inverse to tenderness.
Gluten: Three-dimensional viscoelastic structure of dough formed as gliadin and glutenin in some flour, are hydrated and manipulated.
Gluten-forming potential: Presence of the proteins gliadin and glutenin that may potentially form the elastic gluten structure.
Gluten development: The hydration and manipulation of flour that has gluten potential.
Grain: The cell size, orientation, and overall structure formed by a pattern or structure of gelatinized starch and coagulated protein of flour particles appearing among air cells in batters and dough.
Kneading: To mix dough into a uniform mass by folding, pressing, and stretching.
Leavening: To raise and make light and porous by fermentation or nonfermentation methods.
Oven spring: The initial rise of batters and doughs subject to oven heat.
Peak: A center tunnel where gases escape from a muffin.
Plastic fat: Solid fat able to be molded to shape, but does not pour.
Proofed: The second rise of shaped yeast dough.
Tender: Having a delicate, crumbly texture, a property of some pastries that is inverse to flakiness.
Tunnels: Elongated air pathway formed along gluten strands in batters and doughs, especially seen in overmanipulated muffins.
Wheat flour: Flour derived from the endosperm of milled wheat.
Whole wheat flour: Flour derived from the whole kernel of wheat; contains bran, endosperm, and germ of wheat.

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PART VII

Aspects of Food Production

CHAPTER 16

Food Safety

INTRODUCTION

“Food is our common ground, a universal experience” (James Beard). However, keep it safe! Food safety is an important issue today as there are many demands on the food production system and a variety of food handlers serving numerous individuals who are immunocompromised.

Providing safe food is the responsibility of many individuals/groups. For example, federal agencies such as the US Food and Drug Administration (FDA) and the US Department of Agriculture (USDA), Centers for Disease Control and Prevention (CDC), as well as the state and local counterparts, numerous professional organizations, food processors, and consumers are all interested in preventing the occurrence of foodborne illness. The FDA ranking of food safety concerns, according to risk, ranks foodborne illness as the primary concern, followed by nutritional adequacy of foods, environmental contaminants, naturally occurring toxicants, pesticide residues, and food additives.

While efforts are made to educate the consumer regarding food safety, hazards in the food supply may be controlled/prevented *before* foods reach the consumer. The effective use of the Hazard Analysis and Critical Control Point (HACCP) method of food safety, practiced in the food processing industry, has been shown to yield safer foods. Irradiation also is employed to reduce the incidence of disease.

As well, pests need control. Aspects of preservation and processing, additives, packaging, and government regulation that contribute to food safety are discussed in Chapters 17–20.

Simulated food defense including training exercises with all levels of the government, nongovernment agencies, and the private sector allow better preparation for and protection against possible contamination of the food supply from terrorist threats. Bioterrorism preparedness training is crucial to food science and food service professionals (www.usda.gov/homelandsecurity). While the achievements of scientists are not readily explained to the public (1), the United States has one of the most diverse and safe food supplies in the world. The food safety of specific food products has been discussed in appropriate chapters throughout this text.

FOODBORNE ILLNESS

Since the FDA ranks foodborne illness as the *primary* food safety concern, this chapter will focus on its *causes* and *prevention* (2),(3). Foodborne illness represents disease carried to people by food and is the result of various biological, chemical, or physical hazards to the food supply. These hazards will be addressed in this chapter.

Foodborne illness typically is due to ingestion of contaminated *animal* products. *Plant* foods may be implicated as a result of airborne, water, soil, insect, or even human contamination when these foods are grown. Recent, national foodborne illness cases have included deaths, as a result of eating contaminated bagged spinach.

Animal and plant foods that support the growth of microorganisms are classified by the FDA as potentially hazardous foods (PHF), defined as follows:

(a) "Potentially hazardous food" means a Food that is natural or synthetic and that requires temperature control because it is in a form capable of supporting:

  (i) The rapid and progressive growth of infectious or toxigenic microorganisms.

  (ii) The growth and toxin production of *Clostridium botulinum*.

  (iii) In shell eggs, the growth of *Salmonella enteritidis*.

(b) "Potentially hazardous food" includes an animal food (a food of animal origin) that is raw or heat-treated; a food of plant origin that is heat-treated or consists of raw seed sprouts; cut melons; and garlic and oil mixtures that are not acidified or otherwise modified.

(c) "Potentially hazardous food" does not include:

  (i) An air-cooled hard boiled egg with shell intact.

  (ii) A Food with a water activity (A_w) value of 0.85 or less.

  (iii) A food with a pH level of 4.6 or below when measured at 75°F (24°C).

  (iv) A food, in an unopened hermetically sealed container, which is commercially processed to achieve and maintain commercial sterility under conditions of nonrefrigerated storage and distribution.

  (v) A food for which laboratory evidence demonstrates that rapid and progressive growth of infectious and toxigenic microorganisms or the growth of *S. enteriditis* in eggs or *C. botulinum* cannot occur, such as a food that has an A_w and a pH that are above the levels specified above which may contain a preservative or other barriers to growth.

(vi) A food that may contain an infectious or toxigenic microorganism or chemical, physical contaminant at a level sufficient to cause illness, but which does not support the growth of microorganisms as specified in the definition of potentially hazardous food.

While *prevention* policies are the first line of defense against hazards, *rapid detection* of biological contaminants is imperative (4) as is proper sanitation (5, 6). The risk of disease must be controlled throughout the steps of manufacturing, processing, storage, and distribution of foods. Today, there is a high interest in improving the safety net of the food supply (7) and testing for bacteria such as *E. coli O157:H7* (8).

Some *examples* of potentially hazardous foods are products that contain

- meat
- poultry
- eggs
- milk
- fish
- shellfish
- some synthetic ingredients
- tofu
- baked potatoes
- cut melon

Both feasting on fear (9) and panicking over pathogens (10) are unwanted actions in combating foodborne illness. The government must regulate the food supply considering scientific and societal forces (11), and both the manufacturer and consumer play vital roles in food safety.

Food manufacturers are significantly involved in food safety. "Quality control and anti-tampering measures developed by the food industry in cooperation with government agencies over the past two decades have made the U.S. food supply the safest in the world. Since the September 11 [2001] attacks, our industry has recognized that we must take additional proactive measures to ensure safety of consumers. The safeguards that we developed to address long-standing food safety issues and past tampering incidents are being reexamined, strengthened and enforced with vigilance in light of these recent events."

Due to the effort of many in industry and the government, the United States has one of the most diverse and safe food supplies in the world. The scientists must be willing to explain their achievements to the public (1).

BIOLOGICAL (MICROBIOLOGICAL) HAZARDS TO THE FOOD SUPPLY

Biological hazards that cause foodborne illness include *microorganisms* such as bacteria, viruses, fungi, and parasites. These may be small in size but can cause serious foodborne illness or death. Biological hazards to food are controlled by the following:

- Temperature—adequate cooking, cooling, refrigeration, freezing, and handling.
- The avoidance of cross-contamination.
- Enforcement of personal hygiene among food handlers.

Bacteria—The Major Biological Foodborne Illness

Of the microbiological hazards, *bacteria* are the *primary* organism implicated in foodborne disease, and therefore are the *primary* microbial concern of many consumers, food processors, microbiologists, and others who are responsible for producing safe food.

The bacteria cause foodborne illnesses by (1) infection, (2) intoxication, or (3) toxin-mediated infection as noted in the following:

Foodborne ***infection*** results from ingesting *living*, pathogenic bacteria such as *Salmonella, Listeria monocytogenes*, or *Shigella* (see Table 16.1).

Foodborne ***intoxication*** results if a preformed *toxin* (poison) is ingested, such as that produced by *Staphylococcus aureus*, *Clostridium botulinum*, and *Bacillus cereus*, is present in the food (Figure 16.1).

A ***toxin-mediated infection*** is caused by ingestion of *living*, infection-causing bacteria such as *C. perfringens* and *E. coli* O157:H7 which also produce a ***toxin*** in the intestine (Table 16.1 and Figure 16.1).

The Educational Foundation of the National Restaurant Association has compiled data on the most common pathogenic or disease-causing bacteria in foods (12). In Figure 16.1, the bacteria name, incubation period, duration of illness, symptoms, reservoir, foods implicated, and means of prevention in foods are presented. An astute manager of a food manufacturing operation (as well as the consumer at home) understands the benefit of having this knowledge and applying this food safety information to their own food products. It promotes customer goodwill and prevents foodborne illness.

Beyond the immediacy of illness, there also is increasing evidence that foodborne gastrointestinal (GI) pathogens may give rise to other illness such as chronic joint disease, ie, arthritis (13).

As is the case of bacteria in general, the bacteria causing foodborne illness need the following elements for growth:

- **protein** (or sufficient nutrients)
- **moisture** [water activity (A_w) above 0.85]
- **pH** (above pH of 4.5, generally neutral—pH 7)
- **oxygen** if aerobic
- a general **temperature** 40–140°F (4–60°C), the ***temperature danger zone*** (TDZ)

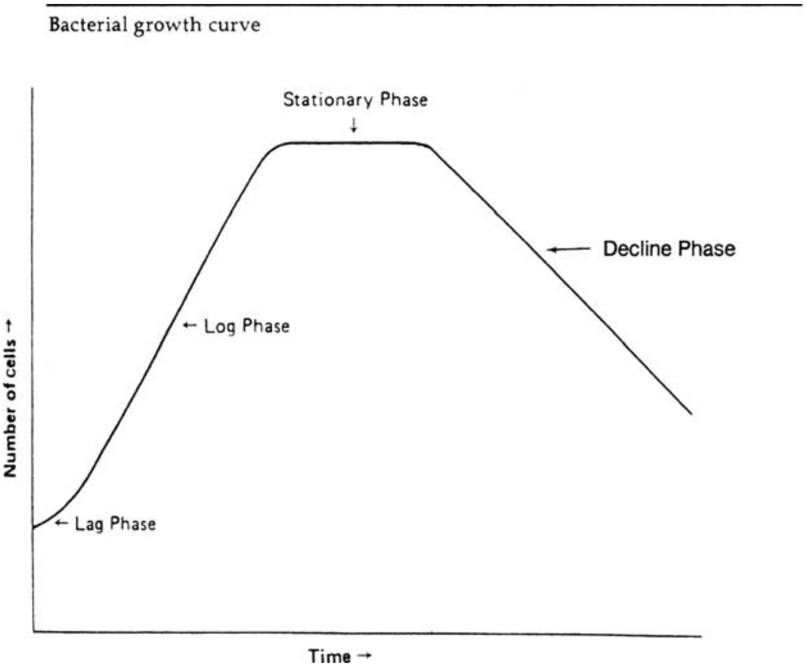

FIGURE 16.1 Bacterial growth curve
(*Source*: Reprinted with permission from *Applied Foodservice Sanitation: A Certification Coursebook*, 4th ed., © 1992. The Educational Foundation of the National Restaurant Association).

(Consult local jurisdiction for specific temperature requirements).

Bacterial growth is portrayed in Figure 16.1. Bacteria vary in their *temperature* requirements, eg, they may be *thermophiles* (high temperatures needed for survival), *mesophiles*, or psychotrophs [cooler temperatures of 50–70 °F (10–20 °C) requirements]. Bacteria also vary in their nutrient needs.

When bacteria are in the tdz, they remain in the *LAG* phase of bacterial growth for approximately 4 hours (cumulative), generally with no increase in number. Then, after the *Lag* phase, the unicellular structure undergoes binary fission and rapid growth in foods that are PHFs. This rapid growth or multiplication of bacteria is termed the *log* (logarithmic) phase of bacterial growth. It is followed by the *stationary* phase, where growth rates approximate death rates and there is no net change in the number of pathogens in the food; and subsequently, by the *decline* phase of bacterial growth, the level of bacteria is reduced.

It is important to recognize the fact that although the end of the *decline* phase may show *less* than the original amount of bacteria, it may contain *more* harmful waste products or toxins that *cannot* be destroyed by cooking. In addition to toxins, the two *Clostridium* bacteria, and *Bacillus cereus* may contain spores (unlike the spores of mold), the highly resistant formations in bacterium that remain in food, even after vegetative cells are destroyed.

TABLE 16.1 Major Foodborne Diseases of Bacterial Origin[a]

	Salmonellosis Infection	Shigellosis Infection	Listeriosis Infection	Staphyloccal Intoxication	*Clostridium perfringens* Toxin Mediated Infection	*Bacillus cereus* Intoxication	Botulism Intoxication
Bacteria	*Salmonella* (facultative)	*Shigella* (facultative)	*Listeria monocytogenes* (reduced oxygen)	*Staphylococcus aureus* (facultative)	*Clostridium perfringens* (anaerobic)	*Bacillus cereus* (facultative)	*Clostridium botulinum* (anaerobic)
Incubation Period	6–72 hours	1–7 days	1 day to 3 weeks	1–6 hours	8–22 hours	1/2–5 hours; 8–16 hours	12–36 hours + 72
Duration of Illness	2–3 days	Indefinite, depends on treatment	Indefinite, depends on treatment, but has high fatality in the immunocompromised	24–48 hours	24 hours	6–24 hours; 12 hours	Several days to a year
Symptoms	Abdominal pain, headache, nausea, vomiting, fever, diarrhea	Diarrhea, fever, chills, lassitude, dehydration	Nausea, vomiting, headache, fever, chills, backache, meningitis	Nausea, vomiting, diarrhea, dehydration	Abdominal pain, diarrhea	Nausea and vomiting; diarrhea, abdominal cramps	Vertigo, visual disturbances, inability to swallow, respiratory paralysis

Reservoir	Domestic and wild animals; also humans, especially as carriers	Human feces, flies	Humans, domestic and wild animals, fowl, soil, water, mud	Humans (skin, nose, throat, infected sores); also, animals	Humans (intestinal tract), animals, and soil	Soil and dust	Soil, water
Foods Implicated	Poultry and poultry salads, meat and meat products, milk, shell eggs, egg custards and sauces, and other protein foods	Potato, tuna, shrimp, turkey and macaroni salads, lettuce, moist and mixed foods	Unpasteurized milk and cheese, vegetables, poultry and meats, seafood, and prepared, chilled, ready-to-eat foods	Warmed-over foods, ham and other meats, dairy products, custards, potato salad, cream-filled pastries, and other protein foods	Meat that has been boiled, steamed, braised, stewed or roasted at low temperature for a long period of time, or cooled slowly before serving	Rice and rice dishes, custards, seasonings, dry food mixes, spices, puddings, cereal products, sauces, vegetable dishes, meat loaf	Improperly processed canned goods of low-acid foods, garlic-in-oil products, grilled onions, stews, meat/poultry loaves
Spore Former	No	No	No	No	Yes	Yes	Yes

(Continued)

TABLE 16.1 *(Continued)*

	Salmonellosis Infection	Shigellosis Infection	Listeriosis Infection	Staphyloccal Intoxication	*Clostridium perfringens* Toxin Mediated Infection	*Bacillus cereus* Intoxication	Botulism Intoxication
Prevention	Avoid cross-contamination, refrigerate food, cool cooked meats and meat products properly, avoid fecal contamination from foodhandlers by practicing good personal hygiene	Avoid cross-contamination, avoid fecal contamination from foodhandlers by practicing good personal hygiene, use sanitary food and water sources, control flies	Use only pasteurized milk and dairy products, cook foods to proper temperatures, avoid cross-contamination	Avoid contamination from bare hands, exclude sick foodhandlers from food preparation and serving, practice good personal hygiene, practice sanitary habits, proper heating and refrigeration of food	Use careful time and temperature control in cooling and reheating cooked meat dishes and products	Use careful time and temperature control and quick chilling methods to cool foods, hold hot foods above 140°F(60°C), reheat leftovers to 165°F(74°C)	Do not use home-canned products, use careful time and temperature control for *sousvide* items and all large, bulky foods keep *sousvide* packages refrigerated, purchase garlic-in-oil in small quantities for immediate use, cook onions only on request

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[a] *Source*: Reprinted with permission form *Applied Foodservice Sanitation: A Certification Coursebook, Fourth ed.* © 1992, The Educational Foundation of the National Restaurant Association.

TABLE 16.2 Emerging Pathogens That Cause Foodborne Illness

	Campylobacteriosis Infection	E. coli0157: H7 Infection/Intoxication	Norwalk Virus Illness
Pathogen	*Campylobacter jejuni*	*Escherichia coli*	Norwalk and Norwalk-like viral agent
Incubation period	3–5 days	12–72 hours	24–48 hours
Duration of illness	1–4 days	1–3 days	24–48 hours
Symptoms	Diarrhea, fever, nausea, abdominal pain, headache	Bloody diarrhea; severe abdominal pain, nausea, vomiting, diarrhea, and occasionally fever	Nausea, vomiting, diarrhea, abdominal pain, headache, and low-grade fever
Reservoir	Domestic and wild animals	Humans (intestinal tract); animals, particularly cattle	Humans (intestinal tract)
Foods implicated	Raw vegetables, unpasteurized milk and dairy products, poultry, pork, beef, and lamb	Raw and undercooked beef and other red meats, imported cheeses, unpasteurized milk, raw finfish, cream pies, mashed potatoes, and other prepared foods	Raw vegetables, prepared salads, raw shellfish, and water contaminated from human feces
Spore former	No	No	No
Prevention	Avoid cross-contamination, cook foods thoroughly	Cook beef and red meats thoroughly, avoid cross-contamination, use safe food and water supplies, avoid fecal contamination from foodhandlers by practicing good personal hygiene	Use safe food and water supplies, avoid fecal contamination from foodhandlers by practicing good personal hygiene, thoroughly cook foods

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[a] *Source*: Reprinted with permission from *Applied Foodservice Sanitation: A Certification Coursebook*, 4th ed., © 1992. The Educational Foundation of the National Restaurant Association.

As mentioned, this makes *prevention* of food contamination the *primary* defense against foodborne illness—harmful substances *cannot* be destroyed in cooking. A careful time–temperature control of potentially hazardous food is required. Refrigeration, for example, *slows* growth and freezing halts growth; however, neither destroys bacteria.

The CDC reports that *improper cooling* of large quantities of food is the number one cause of foodborne illness. (Despite the fact that large quantities of food are in a pot placed in the refrigerator, bacteria do not "know" that they are in the refrigerator. Rather, they are in a large, warm stockpot or steamtable pan and LOVE it, multiplying rapidly!)

Now present in a wide array of products, temperature control is better assured with the use of temperature indicators, including the pop-up type that onceany were used for cooking the traditional holiday turkey. The Food Temperature Indicator Association works with the USDA and food manufacturers to conduct studies regarding temperature and food safety. Specialized timers indicate doneness for a variety of meats and fish.

Today, the USDA's Food Safety and Inspection Service (FSIS) requires that establishments slaughtering cattle, chicken, swine, and turkeys test specifically for bacteria *E. coli*. They must verify the adequacy of process controls for the prevention and removal of fecal contamination and associated bacteria. Additionally, the FSIS has extended such testing to establishments that slaughter species including ducks, equines, geese, goats, guineas, and sheep.

The USDA also has an interest in reduction of the incidence of *Listeria-related* foodborne disease. The *Listeria monocytogenes* is an infectious bacterium that grows in a reduced oxygen environment. Significant legislation may require processors to test for this bacterium on areas (eg, equipment, floors) in/near meat products in plants.

Understanding of the *Listeria* genome has been pursued by the USDA, Agricultural Research Service, which says research information is critical to regulatory their agencies such as FSIS. Regulations for safe processing and handling of ready-to-eat (RTE) foods are created according to this research. Genome study and vaccines for culprits such as *Salmonella* and *E. coli 0157:H7* are underway.

Viruses

In addition to bacteria, although with lesser incidence, viruses also may be responsible for an unsafe food supply and foodborne illness. A virus does *not* multiply in food, as do bacteria, but can *remain* in food if it is insufficiently cooked. Subsequently, viruses infect individuals who ingest it. It is possible for *spot contamination* of food to occur, so that only those individuals consuming the contaminated portion of the food become ill.

A virus of concern to the consumer or a food processing and handling operation, is the *Hepatitis A* virus. A person will become infected with the virus 15–50 days following ingestion of a contaminated product and will shed the virus unknowingly, contaminating *other* people or food *prior* to displaying symptoms of illness. Although the actual infection may last several weeks or months and exhibit symptoms such as abdominal pain, jaundice, and nausea, there are possible widespread and long-lasting financial implications of this illness to the business that is responsible for its spread.

Two sources of the *Hepatitis A* virus are: (1) raw shellfish from polluted water where sewage is discarded, and (2) feces (and urine) of infected persons. To control the first listed source, the growth and harvesting of raw shellfish (clams, oysters, mussels) is regulated by the FDA. The FDA regulates the water beds from which shellfish is harvested. Unfortunately, unreputable suppliers may obtain their shellfish supply from "off-limits" contaminated water, thus harvesting a contaminated product. Also, a *tag* must appear on commercial fresh shellfish to show its source. The tag needs to be retained by the receiver for 90 days.

Control for the second source of the *Hepatitis* virus is that consumers at home and food handlers in food processing or assembly operations, must practice *good personal hygiene*. Just minute amounts of feces may spot contaminate food, causing foodborne illness. Some state or local health department jurisdictions require the use of disposable gloves by food handlers responsible for handling food that is not subject to further cooking.

Thus *Hepatitis A* is of major concern. As seen it is controlled by harvesting from FDA approved water beds, by following good manufacturing practices (GMPs) that include strict personal hygiene after using the restroom and also by proper cooking. Another virus of concern to the consumer and food processing operation is immunodeficiency virus. The CDC states that there is no evidence that this can be transmitted by food. (CDC)

Fungi

Mold and yeast are fungi that may be responsible for spoilage in the food supply.

Mold. The (accidental) ingestion of mold is not known to cause gastrointestinal distress. Rather, it has been implicated in other long-term illness, such as liver cancer, in animals that have been fed moldy crops. Mold obviously causes food spoilage. It also causes loss of food, dissatisfied consumers, and waste of money.

Mold is a multicellular fungus that reproduces by spore formation. After spores form they are then dispersed through the air and may replicate when in contact with food (mold spores are unlike bacterial spores). Mold is the unwanted blue, green, white, and black fuzzy growth on food. It may be considered acceptable in medicine such as penicillin, or some cheeses such as blue cheese. A small percent of persons may fatally suffer from allergies to molds.

Yeast. Yeast is a unicellular structure that grows by the budding process. It causes food *spoilage*, as is evidenced by the formation of pink patches on moist cheeses or cloudy liquid in condiment (such as olives) jars. Foodborne yeast has *not* been shown to cause illness, but nonetheless undesirable growth must be controlled or food is wasted. Yeast shown is *generally* to have beneficial uses in the food industry such as when it leavens baked products or is used in fermentation to produce alcoholic beverages.

Parasites

In addition to bacteria and some fungus, as discussed, parasites may be a source of foodborne illness. Parasites are tiny organisms that depend on living hosts for their nourishment and life. Undercooked pork products may carry the parasite *Trichinella spiralis*, which causes the disease trichinosis. Two days to 28 days following ingestion of the *Trichinella* parasite, an individual may exhibit nausea, vomiting, abdominal pain, and swelling of tissue surrounding the eye. Fever and muscular stiffness then develop. Since pork may be contaminated with this parasite, all pork products must be cooked to 155°F(68°C) [or 170°F(77°C) if cooked in a microwave oven], and all equipment used in its preparation should be sanitized.

Fish from *unapproved* sources may carry the parasite *Anisakis* and result in the parasitic disease anisakiasis. Reputable suppliers to processing plants are the best assurance that the product has been handled safely. Freezing for the correct time and temperature actually can kill *Anisakis*. On the other hand, when fresh fish is served *raw*, food safety takes on new significance!

Contamination, Spoilage

There is a difference between contaminated and spoiled food. The latter may never cause illness due to the fact that it never gets eaten! Illness is more likely to be the result of ingesting unseen microbial (or chemical) contamination. Thus, *contaminated* food that is truly “bad” food is not always apparent to the eye. Impure or harmful substances may be too small or unnoticeable. *Spoiled* food has visible damage to the eating quality of food and is *not* the primary cause of foodborne illness.

Any chance of initial contamination should be prevented and then subsequent growth controlled in order to maintain food safety. Cross-contamination, or the transfer of germs from one contaminated food or place to another by hands, equipment, or other foods, should be avoided.

In addition to those pathogens mentioned, there is the possibility of contamination by emerging pathogens. Their incidence has increased within the last few years and they threaten to increase in the near future.

CHEMICAL HAZARDS TO THE FOOD SUPPLY

All food is made of chemicals and is expected to be safe for consumption (14). However, a chemical hazard to the food supply may occur when dosages or levels of specific chemicals reach toxic levels. Hazards may be accidental, caused by additives by toxic metals, or be naturally occurring.

TABLE 16.3 Control of Chemical Hazards[a]

I. *Control before receipt*. Raw material specifications; vendor certification/guarantees; spot checks—verification

II. *Control before use*. Review purpose for use of chemical; ensure proper purity, formulation, and labeling; Control quantities used

III. *Control storage and handling conditions*. Prevent conditions conductive to production of naturally occurring toxicants

IV. *Inventory all chemicals in facility*. Review uses; records of use

[a] *Source*: Ref. 14.

Chemical contamination includes *accidental* chemical contamination, such as when contents of a container, perhaps unlabeled, are mistakenly used in food. Excessive quantities of *additives* become problematic especially when if an individual has a specific allergy.

Also, included in the list of chemical hazards are toxic *metals* such as galvanized iron. Steel may bond permanently to zinc to the steel through galvanizing. Such zinc-coated material may be used for building fabrication; however, it should be avoided as a food contact surface since it is highly reactive with acids. In the past, containers used for beverages, temporary working surface, and shelving made of toxic galvanized iron had been part of restaurant operations.

One more type of chemical hazard is the animal/plant foodstuff itself. Naturally occurring toxins in some foods such as the puffer fish may cause severe illness.

Control of chemical hazards prior to receipt or use and control in inventory, storage, and handling are identified in Table 16.3. Care must be taken to avoid chemical hazards.

PHYSICAL HAZARDS TO THE FOOD SUPPLY

Physical hazards to the food supply are any *foreign objects* found in food that may contaminate it. Certainly, they are unwanted by the consumer. Certainly they should not be deliberate. They may be present due to harvesting or some phase of manufacturing, or they may be intrinsic to the food, such as bones in fish, pits in fruits, eggshells, and insects or insect parts.

Animals or crops grown in open fields are subject to physical contamination, although hazards may enter the food supply due to a variety of incidences that range from faulty machinery, to packaging wraps, to human error. An astute manager prevents the chance of physical contamination by following good manufacturing practices and using his/her observational skills.

TABLE 16.4 Main Materials of Concern as Physical Hazards and Common Sources[a]

Material	Injury Potential	Sources
Glass	Cuts, bleeding; may require surgery to find or remove	Bottles, jars, light fixtures, utensils, gauge covers
Wood	Cuts, infection, choking; may require surgery to remove	Fields, pallets, boxes, buildings
Stones	Choking, broken teeth	Fields, buildings
Metal	Cuts, infection; may require surgery to remove	Machinery, fields, wire, employees
Insects, other filth	Illness, trauma, choking	Fields, plant postprocess entry
Insulation	Choking, long-term if asbestos	Building materials
Bone	Choking, trauma	Fields, improper plant processing
Plastic	Choking, cuts, infection; may require surgery to remove	Fields, plant packaging materials, pallets, employees
Personal effects	Choking, cuts, broken teeth; may require surgery to remove	Employees

[a] *Source:* Ref. 9. Adaptation from Corlett (1991).

The main materials of concern as physical hazards include foreign objects such as glass, wood, metal, plastic, stones, insects and other filth, insulation, bones, and personal effects (15) (Table 16.4). Modern optical scanning technologies are capable of sorting difficult, potential problem products and are designed to minimize such contamination at the processing plant. Devices such as screen, filters, magnets, and metal detectors may be used online or throughout the manufacturing plant to search for foreign objects and avert health disasters or product recalls. X-ray units are reliable in detecting a variety of objects (Figures 16.2).

Metal detectors are designed to detect metals in liquid, solid, granular, or viscous food products and in various packaging trays and wraps .The use of the common X-ray, a 40-year-old technology, is now a quality assurance tool in the inspection of finished food products. Its use may be a requirement of vendors supplying their foods to a warehouse club. Continual developments make it more affordable, compact and faster to use in the manufacturing plant (16).

FIGURE 16.2 Metal detector
(*Source:* Advanced Detection Systems).

Personal effects, such as jewelry, may not be worn in the production areas. Personnel rules such as "no gum chewing" and "cover hair" need to be enforced in the workplace.

Physical hazards may harm a consumer's health, cause psychological trauma, or dissatisfaction. Ill, upset, or dissatisfied consumers may call or write to the responsible manufacturer or processor, contact the food service establishment, or involve the local health department in investigating their complaint. Any chance of physical objects getting into the food supply should be prevented.

Foreign substance laboratories in food manufacturing companies as well as personnel in food service establishments need to look out for and be informed of any reported food safety problems—chemical or physical so that they may investigate and prevent possible problems. Consumers benefit from this prevention and incidences of contamination are reduced.

FOOD PROTECTION SYSTEMS

Many agency names appear in this section of text addressing food protection systems. While the listing may be lengthy, the names actually represent only a portion of the many groups responsible for the United States' food safety—considered the safest in the world.

The CDC, FDA, the USDA's FSIS, and state and county health departments have regulatory authority for food protection and they provide education to the public. There also are numerous trade associations and professional organizations involved in providing education and protecting the public from foodborne illness. Examples of these associations and organizations are listed at the end of this chapter.

In 1998, a federal, interagency group was created in the United States to improve the safety of the food supply. This President's Council on Food Safety (PCFS) was composed of departments such as the Department of Agriculture, Commerce, Health and Human Services, Management and Budget. It also included the Environmental Protection Agency. A coordination of inspection, enforcement, and research was made possible, as was food safety education.

Food companies also maintain extensive food protection systems. When food companies were asked to rank the areas of food science that they thought were most important, safety concerns were reported 3rd and 5th in the ranking as follows:

1. Developing healthy foods
2. Nutraceutical or medical foods
3. *Food safety* from a process standpoint
4. Developing "natural" foods
5. *Food safety* from an ingredient selection point of view
6. Organic food development
7. Reduced fat/altered lipids development
8. Methods development for quality control (15)

Eliminating or reducing the biological, chemical, and physical hazards to the food supply is the goal of food safety. In the quest to destroy pathogens, for example, the FDA approved irradiation of meat in 1997, as it was shown to yield safer meat than meat that is not irradiated (17). Irradiation, both off-site and online also is being utilized as a means of food safety for a wide array of food items (18). Such treatment of refrigerated or frozen raw meat and meat products (eg, sausages, bologna) was approved in the year 2000. Additionally, high-pressure processing (eg, 20,000–80,000 p.s.i and higher) is used for food products such as guacamole, meats, and seafood processing, including raw oysters. High-pressure sterilization is being considered (19) for added food safety.

Although they may not provide *real-time* information, processing plants may use statistical analysis to define acceptable upper and lower control limits, and then use this information to improve product quality. Statistical process control (SPC) provides advances in microbiological analyses, which in turn will allow the manufacturing process to integrate testing with quality improvement and productivity (20). SPC also may be integrated with the hazard analysis and critical control point (HACCP) method of food safety (discussed below).

In addition to this manufacturing concern, many food service operations have sent at least one manager to local training in food protection management.

Many news shows and magazines have addressed the issue of food safety for consumers.

The Food and Drug Administration (FDA) and the Centers for Disease Control and Prevention (CDC) of the US Department of Health and Human Services (HHS) and the Food Safety and Inspection Service of the US Department of Agriculture (USDA) released the 2005 edition of the Food Code. The 2005 Food Code may be viewed at:

http://www.cfsan.fda.gov/%7Edms/fc05-toc.html presents the Food Code: It covers:

Chapter 1. Purpose and Definitions
Chapter 2. Management and Personnel
Chapter 3. Food
Chapter 4. Equipment, Utensils, and Linens
Chapter 5. Water, Plumbing, and Waste
Chapter 6. Physical Facilities
Chapter 7. Poisonous or Toxic Materials
Chapter 8. Compliance and Enforcement

THE HACCP SYSTEM OF FOOD PROTECTION

In order to reduce foodborne illness risks from biological, chemical, or physical hazards, the *hazard analysis and critical control point—HACCP* (pronounced hassip)—system of food safety may be required for use by food processors and food service operations (Table 16.5). The system depends on *prevention* rather than *inspection*.

In fact, the "mega-reg" or pathogen reduction: hazard analysis and critical control point system regulation was signed by the US President in 1996. It codified principles for the prevention and reduction of pathogens and required both the development of sanitation standard operating procedures (SSOPs) and a written HACCP plan that is monitored and verified by inspectors of various food processing plants. Compliance deadlines were phased in, depending on the size of the company.

FSIS tests raw livestock and poultry in the slaughtering processes for *Salmonella* and *E. coli*. Seafood HACCP became effective in 1997. Juice processors must have HACCP. Later, HACCP plans for protection against *L. monocytogenes* in ready-to-eat meat products were required by the FSIS. Currently, egg processors, as well as dairy plants and additional industries, have implemented HACCP.

HACCP traces the flow of food from entry into an operation through exit. It does more than *detect and correct* errors *after* they have occurred; as mentioned, it is a program that *prevents* errors regarding food safety before they occur. By definition of a quality assurance (QA) program, HACCP may not fit QA. Sanitation is typically a separate program at a food manufacturing facility and is not put into the same category as other aspects of food quality. Sanitation is a 24/7 duty and may compose the entire third shift of a 24-hour food manufacturing plant.

HACCP was originally designed by the Pillsbury Company, in cooperation with Natick Laboratories of the US Army and the US Air Force Space Laboratory Project Group. The system was designed for use by the National Aeronautics and Space Administration (NASA) Program. HACCP has been used as a food safety system in the food industry since 1971, and it offers practical food protection techniques that are needed anywhere food is prepared or served.

The National Advisory Committee for Microbiological Criteria for Foods (NACMCF) (21) has identified seven major steps involved in the HACCP

TABLE 16.5 Steps of a Hazard Analysis and Critical Control Point (HACCP) Program

I. **Assessing the hazards**
Hazards are assessed at each step in the flow of food throughout an operation.

II. **Identifying critical control points (CCPs)**
Identify CCPs regarding hygiene, avoiding cross-contamination, and temperatures and procedures for cooking and cooling. A flowchart of preparation steps is developed, showing where monitoring is necessary to prevent, reduce, or eliminate hazards.

III. **Setting up control procedures and standards for critical control points**
Establish standards (criteria) for each CCP and measurable procedures such as specific times and temperatures, moisture and pH levels, and observable procedures such as hand washing.

IV. **Monitoring critical control points**
Checking to see if criteria are met is one of the most crucial steps in the process. Assigning an employee to monitoring temperatures of storage, cooking, holding, and cooling are necessary to see if controls against hazards are in place.

V. **Taking corrective action**
Observe if there is a deviation between actual and expected results. Correct the procedures by using an alternate plan if a deficiency or high-risk situation is identified in using the original procedure. This may be accomplished by a trained employee empowered to initiate corrective action without a supervisor being present.

VI. **Develop a record-keeping system to document HACCP**
Time–temperature logs, flowcharts, and observations are used for record-keeping.

VII. **Verify that the system is working**
Make use of time and temperature logs completed during preparation, holding, or cooling. Observe.

system (Table 16.5). HACCP can be used in multiple spots within the food chain; for example, in growing, harvesting, processing, preparing, or serving of foods.

With the establishment of an HACCP Program, new terminology may be used; some selected HACCP definitions are given in Table 16.6. A written HACCP plan (22) is based on the principles of HACCP and delineates the procedures to be followed to assure the control of a specific process or procedure. A HACCP team (23) is responsible for developing an HACCP plan, and as a result of implementing the HACCP plan, the company has an HACCP system (Table 16.6).

Using the HACCP system, the HACCP team first must identify potentially hazardous foods that are prepared in their operation. Then, they must observe the flow of potentially hazardous foods from the acquisition of raw ingredients to completion of the finished product, especially studying the flow of sensitive ingredients known to have been associated with a hazard and for which there is a reason for concern. This observation leads to the development of a flowchart (Tables 16.7–16.10).

After identifying those foods that are potentially hazardous and creating a flowchart, management needs to identify specific, measurable critical control points (CCPs). In the absence of CCPs, food is subject to *unacceptable* risks or likelihood of a hazard.

Next, control procedures and criteria for critical limits must be established and then *monitored* by individual assigned responsibility for tracking CCP procedures. The CCPs may include temperature of the food product and processing equipment; time of processing, package integrity, and more. Measurements and observational skills are employed in order to reveal any unacceptable deviations between actual and expected results. Deviation may require corrective action in order to prevent foodborne illness.

A view of the headings on the food service HACCP of chicken salad and ribs HACCP (Tables 16.7 and 16.8), indicates several major concepts. First, the flow process of foods from the point of receiving food until it is discarded is drawn. Second, the CCPs are identified and then criteria for control are established and briefly stated for ease of understanding. Criteria for control specify such factors as minimum and maximum temperatures that must be reached, correct storage procedures, instructions for personal hygiene and equipment sanitation, and discard rules.

Note that the monitoring and verifying the HACCP program includes instructions to follow for assurance of compliance with criteria. It may be taking temperatures, measuring time to complete preparation, measuring depth of storage pans, or observing procedures that are used in preparation or storage. The entire HACCP process also states the action to be taken if the criteria are not met. HACCP systems require that a designated individual using reliable tools/instruments must monitor the CCPs. The reliability of instruments such as thermometers or thermocouples must be validated.

Handling a PHF requires knowledge of the flow process and how to keep food safe. For example, in *receiving* chicken, the corrective action to take if established

TABLE 16.6 Selected HACCP Definitions (Health and Human Service)

- *Control point:* Any point, step, or procedure at which biological, physical, or chemical factors can be controlled.
- *Corrective action:* Procedures to be followed when a deviation occurs.
- *Critical control point* (CCP): A point, step, or procedure at which control can be applied and a food safety hazard can be prevented, eliminated, or reduced to acceptable levels.
- *Critical limit:* A criterion that must be met for each preventive measure associated with a critical control point.
- *Deviation:* Failure to meet a critical limit.
- *HACCP Plan:* The written document which is based on the principles of HACCP and which delineates the procedures to be followed to assure the control of a specific process or procedure.
- *HACCP system:* The result of the implementation of the HACCP plan.
- *HACCP team:* The group of people who are responsible for developing an HACCP plan.
- *Hazard:* A biological, chemical, or physical property that may cause a food to be unsafe for consumption.
- *Monitor:* To conduct a planned sequence of observations or measurements to assess whether a CCP is under control and to produce an accurate record for future use in verification.
- *Risk:* An estimate of the likely occurrence of a hazard.
- *Sensitive ingredient:* An ingredient known to have been associated with a hazard and for which there is reason for concern.
- *Verification:* The use of methods, procedures, or tests in addition to those used in monitoring to determine if the HACCP system is in compliance with the HACCP plan and/or whether the HACCP plan is working.

criteria are not met would be to reject the products upon delivery. In *storage*, the product may require a lower air temperature if the established criteria for maximum temperature were not met. A further *cooking* criteria requires that chicken reach a minimum temperature of 165 °F(74° C). If the temperature is not met at an initial check for doneness, the chicken must continue to be cooked until that temperature is reached. Thus the HACCP *continues* with corresponding action to take for *each* criteria if the criteria is not met and includes corrective practices for handling, personal hygiene, equipment sanitation, food storage, and discarding food.

TABLE 16.7 Hazard Analysis Critical Control Point Flow Process Food: Chicken Salad[a]

Flow Process	CCP	Criteria for Control	Monitor & Verify	Action to Take If Criteria Not Met
Receive refrigerated whole chickens		-Maximum 45°F internal temperature	-Take internal meat temperature with metal stem thermometer	-Reject product
Store in walk-in-cooler (WIC)		-Maximum 45°F internal temperature -Store chickens off floor -Prevent cross-contamination -Air temperature 40°F or less	-Observe proper storage practices -Monitor air temperature each shift-record on log	-Store chicken in approved manner -Lower air temperature
Boil chickens	CCP	-Minimum 165°F internal temperature of meat	-Take internal meat temperature -Observe cooking time	-Cook chicken until temperature is reached
Cool to debone (30 minutes in WIC)		-Do not cover chickens	-Observe storage in WIC	-Store chicken to allow rapid cooling to debone
Debone/dice chicken meat	CCP	-Clean hands or gloves used to handle meat -No infected wounds or bandages on hands -Wash and sanitize equipment used after completion	-Observe handling procedures -Inspect employee hands daily -Observe proper cleaning of equipment	-Instruct workers to wash hands or use gloves -Remove worker or require gloves -Have equipment rewashed
Mix ingredients (mayo, sour cream, relish, spices, meat)		-Use utensils for mixing -Limit time for preparation of meat salad—refrigerate when completed -Use refrigerated ingredients	-Observe use of utensils -Measure time to complete preparation process -Observe use	-Correct practice -Modify procedures to limit time at room temperature -Change practice
Store 1/3 of salad in prep cooler Store 2/3 of salad in WIC (use 1/2 each day at prep cooler)	CCP	-Cool to 45°F within 4 hours after preparation -Maximum 45°F internal temperature in storage -Store salad 3 inches or less in pans -Air temperature 40°F or less	-Measure salad temperature periodically to determine cooling rate -Take internal temperature -Measure depth of salad stored in pans -Monitor air temperature each shift—record on log	-Remove excess salad from pan -Lower air temperature -Store in coolest part of cooler
Sell				
Discard after 3 days from preparation		-Old salad not mixed with fresh salad -Discard remaining salad	-Observe storage process -Observe salad discarded	-Correct practice -Discard salad

[a] *Source:* Alvin Black, R.S. City of Farmers Branch, Environmental Health Division. Farmers Branch, TX.

TABLE 16.8 Hazard Analysis Critical Control Point Flow Process Food: BBQ Ribs

Flow Process	CCP	Criteria for Control	Monitor & Verify	Action to Take if Criteria Not Met
Frozen beef ribs Thaw in walk-in-cooler (WIC)		-Received frozen -Meat thawed under refrigeration -Store meat off floor	-Feel if frozen upon delivery -Observe ribs stored in WIC -Observe proper storage practices	-Reject if thawed -Store ribs properly to prevent contamination or cross-contamination
Cook in oven (add BBQ sauce)	CCP	-Minimum 140°F internal temperature of ribs	- Take internal meat temperature with metal stem thermometer -Observe cooking time and oven temperature	-Cook ribs until temperature is reached
Hold at steam table with overhead heat lamp	CCP	-Minimum 140°F internal temperature	-Take temperature of meat every 2 hours — record on log	-Reheat ribs -Discard ribs if held below 130°F over 2 hours -Check equipment
Sell				
Leftover ribs cooled in WIC overnight	CCP	-Cool from 140° to 45°F within 4 hours	-Measure meat temperature periodically to determine cooling rate in WIC	-Remove excess ribs from pan -Lower air temperature
		-Store meat 3 inches or less in pans	- Measure depth of meat stored in pan -Monitor air temperature of WIC each shift—record on log	-Remove covers - Eliminate stacking
		-No tight cover during cooling process	-Observe meat uncovered during cooling process	-Move ribs to coolest part of WIC -Discard inadequately cooled ribs
		-Do not stack pans -Store meat close to fans in WIC -Air temperature 40°F or less		
Reheat in convention oven next morning	CCP	-Minimum 165°F internal temperature within 2 hours	-Take internal meat temperature with metal stem thermometer	-Reheat meat until temperature is reached
		-Leftovers not mixed with fresh ribs -Discard remaining ribs	-Observe reheating time and oven temperature -Observe meat discarded	-Discard meat
Steam table		-Same instructions as above		
Sell				
Discard by 6:00 p.m.		-Leftovers not mixed with fresh ribs -Discard remaining ribs	- Observe storage process -Observe meat discarded	-Correct practice -Discard meat

[a] *Source:* Alvin Black, R.S. City of Farmers Branch, Environmental Health Division. Farmers Branch, TX.

TABLE 16.9 HACCP. Basic Beef Chili[a]

Ingredients	Amount	25	50	100
Lean ground Beef	Lb	7	14	28
Canned tomatoes	Qt	1 1/2	3	6
Canned kidney beans	Qt	1 3/3	3 1/2	7
Tomato paste	Cups	1 3/3	3 1/2	7
Water	Gal	1/2	1	2
Dehydrated onions	Oz	1	2	4
Chili powder	Tbsp	3	6	12
Sugar	Tbsp	1 1/4	2 1/2	5
Cumin	Tbsp	2	4	8
Garlic powder	Tbsp	1	2	4
Onion powder	Tbsp	1	2	4
Paprika	Tbsp	1	2	4
Black pepper	Tbsp	1/2	1	2

Preparation

1. **CCP** Thaw ground beef under refrigeration (41 °F, maximum 1 day).
2. Place ground beef in steam kettle or in large skillet on stove top. Cook meat using medium high heat until lightly browned (15 minutes). While cooking, break meat into crumbs of about 1/2″ to 1/4″ pieces.
3. Drain meat well, stirring while draining to remove as much fat as possible. If desired, pour hot water over beef and drain to remove additional fat.
4. Mash or grind canned tomatoes with juice. Add to kettle or stock pot with cooked ground beef. Add remaining ingredients to mixture and stir well.
5. **CCP** Simmer chili mixture for 1 hour, stirring occasionally. Temperature of cooked mixture must register 155 °F or higher.
6. Remove from heat and portion into service pans.
7. **CCP** Cover and hold for service (140 °F, maximum 1 hour).
8. Portion: 1 cup (8 ounces) per serving.

Service:
1. **CCP** Maintain temperature of finished product above 140 °F during entire service period. Keep covered whenever possible. Take and record temperature of unserved product every 30 minutes. Maximum holding time, 4 hours.

Storage:
1. **CCP** Transfer unserved product into clean, 2-inch deep pans. Quick-chill. Cooling temperature of product must be as follows: from 140° to 70 °F within 2 hours and then from 70° to 41 °F or below, within an additional 4 hour period. Take and record temperature every hour during chill-down.
2. **CCP** Cover, label, and date. Refrigerate at 41 °F or lower for up to 10 days (based on quality maintained) or freeze at 0 °F for up to 3 months.

Reheating:
1. **CCP** Thaw product under refrigeration, if frozen (41 °F).
2. **CCP** Remove from refrigeration, transfer into shallow, 2- inch deep pans and immediately place in preheated 350 °F oven, covered. Heat for 30 minutes or until internal temperature reaches 165 °F or above.

Discard unused product.

[a] *Source*: La Vella Food Specialists St. Louis, MO.

TABLE 16.10 HACCP. Chicken Stew[a]

Ingredients	Amount	25	50	100
Chicken Pieces, 8 cut, frozen	Lb	10	20	40
Carrots, fresh, peeled, cut in 3/3 inch pieces	Lb	2 ½	5	10
Onions, chopped	Qt	½	1	2
Potatoes, peeled, cut into 3/3 inch pieces	Lb	3 3/3	7 ½	15
Green peas, frozen	Lb	2	4	8
Margarine	Cups	½	1	2
Flour	Cups	1 ½	3	6
Chicken stock	Qt	1	2	4
Salt	Tsp	1	2	4
Pepper	Tsp	1	2	4

Preparation

1. **CCP** Thaw raw chicken pieces under refrigeration (41 °F, 1 day).
2. **CCP** Wash carrots, onions, and potatoes under cool running water. Cut as directed. Use immediately in recipe or cover and refrigerate until needed (41 °F, maximum 1 day).
3. Place chicken pieces on sheet pans. Cover and bake in preheated 350 °F conventional (325 °F convection) oven for 30 minutes.
4. Cook potatoes, carrots, and peas separately in steamer or on stovetop, until tender (4–15 minutes).
5. Remove chicken from oven; drain off juices and fat. Place in 4-inch deep steamtable pans, cover, and return to heated oven (while preparing gravy).
6. In stockpot over medium heat, melt margarine and sauté onions until tender. Add flour and stir until smooth. Add chicken drippings, stirring well. Add chicken broth as needed for gravy-like consistency. Season with salt and pepper. 7. Add cooked vegetables and gravy to chicken pieces. Cover, place back in 350 °F conventional (325 °F convection) oven and bake for 30 minutes or until chicken pieces are tender and sauce is flavorful.
8. **CCP** Internal temperature of cooked stew must register 165 °F for 15 seconds at end of cooking process.
9. **CCP** Cover and hold for service (140 °F, maximum 1 hour).
10. Portion: 1–2 pieces of chicken, ½ cup vegetables with gravy (10 ounces) per serving

Service:
1. **CCP** Maintain temperature of finished product above 140 °F during entire service period. Keep covered whenever possible. Take and record temperature of unserved product every 30 minutes. Maximum holding time, 4 hours.

Storage:
1. **CCP** Transfer unserved product into clean, 2-inch deep pans. Quick-chill. Cooling temperatures of product must be as follows: from 140° to 70 °F within 2 hours and then from 70° to 41 °F or below, within an additional 4 hours. Take and record temperature every hour during chill-down.
2. **CCP** Cover, label, and date. Refrigerate at 41 °F or lower for up to 10 days (based on quality maintained) or freeze at 0 °F for up to 3 months.

Reheating: 1. **CCP** Thaw product under refrigeration, if frozen (41 °F).
2. **CCP** Remove from refrigeration, transfer into shallow, 2-inch deep pans and immediately place in preheated 350 °F oven, covered. Heat for 30 minutes or until internal temperature reaches 165 °F or above.

Discard unused product.

[a] *Source*: La Vella Food Specialists St. Louis, MO.

Identifying such items as the flow process of food, stating CCPs and criteria for control, monitoring, and verifying, and specifying action to take if the criteria are not met, all function to assist management in controlling the spread of disease. Applying a HACCP system to food manufacturing or the food service operation is an effective means of reducing the likelihood of foodborne illness. HACCP is so much more than inspection, and to be effective it requires dedication and perseverance on the part of employees and management.

In *food manufacturing plants*, manufacturers must take steps to ensure that food is safe! They must do so, by law. As a result of taking those critical steps, only a *small* percentage of all foodborne illness cases is linked to poor processing practices. A *greater* number of cases are the result of faulty practices in food service operations and the home. Many state and local health departments have adopted rules for *food service establishments* also, requiring knowledge of foodborne illness and HACCP principles. These food service establishments include hospitals, restaurants, retail grocery stores, and schools.

An example of HACCP plans for food service operations has been shown for chicken salad and BBQ beef ribs. An example of HACCP programs appears in the literature for supermarkets (24); for meat and poultry companies (25), and so forth.

In addition to the HACCP flow process charts mentioned, samples of *two written recipes* that incorporate the HACCP principles appear in Tables 16.9 and 16.10. These recipes demonstrate ways in which a food service operation may include CCPs in preparation steps and flowcharts. For example, an acceptable method of defrosting, cooking, and holding is stated after labeling the preparation step as a CCP, and CCPs are highlighted in the flowcharts.

"In a nutshell, HACCP (pronounced hassip) is a preventive system that identifies, monitors, and controls to ensure food safety by preventing or reducing the likelihood of foodborne illness. To achieve this, every member of an organization in which food items are a factor must be informed and involved. This includes awareness of the existence of pathogenic microorganisms and chemical residue, implementation of proper sanitation measures for physical objects and employee personal hygiene, and avoidance of food supply adulteration and cross contamination at all stages of the distribution, storage, and preparation process" (26).

Today, *numerous* foods are processed in manufacturing plants (Table 16.11) and are distributed to operations such as retail grocery stores, hotels, restaurants, or institutional operations. These foods must provide assurance of food quality, including *microbiological (M), chemical (C), and physical (P)* safety, and must have critical limits, including meeting all safety specifications prior to shipping, measuring temperatures of incoming and chilled ingredients with calibrated instruments, using microbiological tests for food contact surfaces and the environmental area, sanitizing equipment, storing, refrigerating palletizing products, distribution, and labeling.

A revised HACCP model designed by the Food Safety and Inspection Service (FSIS) has shown improvements in food safety. Young chicken plants have demonstrated a greater achievement of performance standards in FSIS verification checks over traditional slaughter inspection (FSIS).

TABLE 16.11 Ingredients of Refrigerated Chicken Salad (Pierson and Corlett)[a]

CCP Number	CCP Description	Critical Limit(s) Description
1-MPC	Hazard controlled:	1.1 Sanitary condition
	Microbiological, physical, and chemical	1.2 Refrig. material <= 45°F
		1.3 Frozen material <= 32°F
	Point or procedure: Incoming inspection	1.4 Vendor met all safety specifications before shipping
2-T	Hazard controlled: Microbiological	2.1 Material internal temperature not to exceed 45°F
	Point or procedure: Refrigerated	
	Ingredient storage	2.2 Calibrate temperature-measuring devices before shift
3-M	Hazard controlled: Microbiological	3.1 Comply with USDA sanitation requirements
	Point or procedure: Sanitation requirements in	
		3.2 Sanitation crew trained
	• Preparation area	3.3 Each area must pass inspection before shift startup
	• Staging area	
	• Filling/packaging area	
	Hazard controlled:	3.4 Food contact surface: Microbiological test
	Point or procedure: *Listeria*	
		3.5 Environmental area: Microbiological tests (USDA Methodology for 3.4 and 3.5)
4-M	Hazard controlled: Microbiological	Application of alternative approved treatments
	Point or procedure: Controlled treatment to reduce microbiological contamination on raw celery and onions	
		4.1 Wash product with water containing • Chlorine, or • Iodine, or • Surfactants, or • No process additives

		4.2 Hot water or steam blanch followed by chilling
		4.3 Substitute processed celery or onions: • Blanched frozen • Blanched dehydrated • Blanched canned
5-M	Hazard controlled: Microbiological	5.1 Not to exceed 45°F
	Point or procedure: Chilled storage temperature of prepared celery, onions, and chicken	5.2 Refrigerator not to exceed 45°F
		5.3 Daily calibration of temperature measuring devices
6-MPC	Hazard controlled: Microbiological, physical, and chemical point or procedure: Physical barrier to prevent cross-contamination from raw material preparation area	6.1 Physical barrier in place
		6.2 Doors kept closed when not in use
		6.3 Color-coded uniforms
		6.4 Supervision in place
7-M	Hazard controlled: Microbiological point or procedure: Cross-contamination prevention from transfer equipment from raw material area	7.1 Comply with USDA sanitation requirements
		7.2 Prevent entry of soiled pallets, cart wheels, totes, and other equipment
8-M	Hazard controlled: Microbiological	8.1 Time limit not to exceed 4 hours for any materials in staging area
	Point or procedure: Time limit for in-process food materials	
9-M	Hazard controlled: Microbiological	9.1 Product pH must not exceed a pH of 5.5
	Point or procedure: Maximum pH limit on finished salad before packaging	9.2 pH meter must be calibrated with approved standards before each shift
10-M	Hazard controlled: Microbiological	10.1 Internal temperature not to exceed 45°F
	Point or procedure: Chilled product storage temperature and time before packaging	10.2 Product must not be held more than one shift before filling/packaging

(Continued)

TABLE 16.11 *(Continued)*

CCP Number	CCP Description	Critical Limit(s) Description
11-P	Hazard controlled: Physical point or procedure: Metal detector for packages	11.1 Ferrous metal detection device for individual packages 11.2 Calibration or inspection not to exceed every 4 hours
12-M	Hazard controlled: Microbiological Point or procedure: Physical barrier to prevent cross-contamination from warehouse area	12.1 Physical barrier in place 12.2 Doors kept closed when not in use 12.3 Color-coded uniforms 12.4 Supervision in place
CCP Number	CCP Description	Critical Limit(s) Description
13-M	Hazard controlled: Microbiological Point or procedure: Refrigerated storage of cased/palleted finished product	13.1 Product internal temperature not to exceed 45°F in 4 hours 13.2 Temperature measuring devices calibrated before shift
14-M	Hazard controlled: Microbiological Point or procedure: Truck and shipping containers for distribution of finished product	14.1 Shipping compartments must be precooled to 45°F or less before loading product
15-M	Hazard controlled: Microbiological Point or procedure: Label instructions	15.1 Each package or bulk case shall have label instructions 15.2 Each label shall include: • Keep refrigerated • Code • Storage instructions

source: Pierson MD, Corlett DA.
HACCP Principles and Applications;
M = microbiological hazard;
P = physical hazard;
C = chemical hazard.

Using research data from testing in large plants over a two-year period, the FSIS reports that there are substantial reductions in the prevalence of *Salmonella* compared to pre-HACCP baseline figures in raw meat and poultry. A 50% decrease was shown in young chicken and swine carcasses, and more than 30% reduction was reported for ground turkey. One year of testing in small plants also showed decreases in *Salmonella*—40% in ground beef, approximately 20% in young chicken carcasses, and 15% in cow and bull carcasses, but data showed an increased incidence in swine carcasses (USDA).

Good food protection systems may rely on government agencies, or programs including HACCP. However, it should be noted that there is no substitute for maintaining good personal hygiene in the workplace! One automatic handwashing system that meets both HACCP requirements, and busy employee standards, is complete "touchless" handwashing (Meritech. Golden, Colorado).

SURVEILLANCE FOR FOODBORNE-DISEASE OUTBREAKS

The FDA estimates of foodborne diseases have been reported to be in the tens of millions, while the actual report of cases to the CDC is in the thousands. Since all illnesses are*not* reported, the true number is unknown.

Since 1973, the CDC has maintained surveillance data regarding the occurrence and causes of foodborne disease outbreaks (FBDOs). Now, the CDC actively surveys emerging foodborne diseases. The Foodborne Diseases Active Surveillance Network (FoodNet) is the primary foodborne disease component of the CDC's Emerging Infections Program (EIP). It began in the mid-1990s with five states and now includes many more states, representing over 25.4 million persons (more than 10% of the United States population).

FoodNet looks at seven bacteria and viral foodborne pathogens, including *Salmonella, Shigella, Campylobacter, E. coli 0157, L. monocytogenes, Yersinia enterocolitica*, and *Vibio*, and parasites such as *Crytosporidium and Cyclospora.* The CDC program is designed to assist public health officials to better understand the epidemiology of foodborne diseases.

The goals of FoodNet are as follows:

- Describe the epidemiology of new and emerging bacterial, parasitic, and viral foodborne pathogens.
- Estimate the frequency and severity of foodborne diseases that occur in the United States per year.
- Determine how much foodborne illness results from eating specific foods, such as meat, poultry, and eggs.

FoodNet is different from other foodborne disease surveillance systems. It does not rely on current "passive" surveillance systems, with the complexities of reporting by clinical laboratories to state health departments and then on to the CDC. Rather, it is an "active" reporting system where public health officials frequently contact laboratory directors for data which are then electronically transmitted to the CDC. It has five components:

- Active laboratory-based surveillance
- Survey of clinical laboratories
- Survey of physicians
- Survey of the population
- Epidemiologic studies

Their "*burden of foodborne disease pyramid*" follows these hierarchical steps, beginning at the base with an initial report to the Health Department/CDC:

Exposures in the general population
Person becomes ill
Person seeks care
Specimen obtained
Lab tests for organism
Culture-confirmed case
Reported to Health Department/CDC

The reporting data appear several years after the occurrence of illness, and the most current data were reported through 2004. Recent summary statistics are found at the CDC:

http://www.cdc.gov/foodborneoutbreaks/outbreak_data.htm.

A recent report states 1,319 outbreaks, and 28,239 cases. Where the etiology was determined in outbreaks, it was as follows:

- Bacterial pathogens caused the largest percentage of outbreaks 208 outbreaks and 5,269 cases. Salmonella accounted for the largest number of outbreaks, cases, and deaths, most of which were attributable to undercooked, infected eggs.
- Viruses caused 251 outbreaks and 9,994 cases.
- Parasites caused 8 outbreaks and 230 cases.
- Chemical agents caused 47 outbreaks and 153 cases.
- Multiple etiologies accounted for 5 outbreaks, and 726 cases.

The number of foodborne disease outbreaks (FBDOs) is reported by state and territorial health departments to the CDC on a standard reporting form. The definition of FBDO is "two or more cases of a similar illness resulting from the ingestion of a common food," whereas prior to 1991, it was one case of intoxication by chemical, marine toxin, or *C. botulinum* toxin as a result of the ingestion of food.

Many individuals who become ill do *not* relate it to food consumption or report this incident to appropriate authorities. Therefore, perhaps only a small percentage of actual FBDOs are reported. Nonetheless, surveillance data provide "an indication of the etiologic agents, vehicles of transmission, and contributing factors associated with FBDO and help direct public health actions."

Persons most "at-risk" for, or likely to become ill with, a foodborne illness include the elderly (the largest risk segment of the US population), pregnant and nursing women, school-age children, and infants. These are represented as "highly susceptible populations." As well, increasing numbers of persons testing positive for the human immunodeficiency virus (HIV), persons with acquired immunodeficiency syndrome (AIDS), or persons with a weakened immune system due to pharmaceutical or radiological treatment are very susceptible to illness.

The growth of the *number* of persons at risk, coupled with a greater *number* of meals eaten away from home, provides *increasing* opportunities for the occurrence of foodborne illness. Controlling hazards and ensuring a safe food supply is possible through such methodologies as the use of an HACCP system and employee training. It is recommended that FSIS should seek authority to impose monetary penalties for violations and do a better job of monitoring test procedures (28).

The CDC Guide to Confirming a Diagnosis in Foodborne Disease is located in: http://www.cdc.gov/foodborneoutbreaks/guide_fd.htm

OTHER CAUSES OF SPOILAGE AND CONTAMINATION

In addition to the biological, chemical, and physical hazards that may contaminate the food supply, enzymatic activity and exposure to excessive moisture spoil food. Pests also contaminate food, perhaps making it noticeably nonedible due to droppings. Cockroaches and insects carry germs, and some insects regurgitate on food with their acidic saliva in order to break it down prior to ingestion. Rodents, for example, do not have bladders and may contaminate all surfaces with which they make contact. Birds are another potential pest problem, perhaps also speading "bird flu". A non-chemical, nearly invisible netting of knotted polyethylene (looks like a chain link fence – Bird X) has been added to the list of what may be used for bird pest control. Regardless, of the type of pest, working with the in-house or other pest contol operator (PCO) is important to keep pests out and away from the food manufacturing or food processing plant.

Throughout the world, in developed and underdeveloped countries, food spoilage may be responsible for a lot of food waste. Diligence in care is a must. Depending on resources and beliefs, preservation (Chapters 17), the use of additives (Chapter 18) and packaging (Chapter 19) are all methods that may be used for controlling undesirable spoilage or contamination.

LABELING AS A MEANS OF ASSURING FOOD SAFETY

Dating

Open dates may be placed by food processors on the food package. This provides the end user with information regarding optimum time periods to keep foods on hand. However, dating is not a guarantee against spoilage or harmful contamination. Personnel in processing and food service operations, as well as consumers, must observe foods for their possible deterioration and not use damaged products.

Open date labeling is *mandatory* for dairy products, but other foods may *voluntarily* have open date labeling. Foods also may display a *code date*, which can be read only by the manufacturer. Some examples of the types of dating that may appear on foods include the following:

- **"Best if used by" date—**informs consumers of the food's optimal period for retention of high quality
- **Expiration date—**indicates a deadline for recommended use
- **Pack date—**indicates when the food was packaged
- **Pull date—**signifies the last day the food may be sold as fresh. All food products should be made available for use only within established time frames.

Allergen-Free Labeling

An issue that relates to food safety is the manufacture of allergen-free foods (Chapter 20). As one author has said "Food safety is being redefined to include allergen-free as well as pathogen-free" (29). The FDA is responsible for ingredient labeling, and has given notice to food processors that exemptions from ingredient labeling would not be tolerated. A food product must contain what it states on the label and it should *not* contain an ingredient it does *not* disclose. Life-threatening allergens must be reported on the food label, and in uncertain cases, statements such as "may contain" are displayed as a safeguard.

The eight major foods to which people have allergies include: milk, eggs, peanuts, tree nuts (eg, almonds, cashews), soy, wheat, fish, and shellfish. These are responsible for 90% of food allergic reactions, and therefore represent ingredients that thus should be isolated in the production process. Severe allergic reactions can cause anaphylaxis or death (Food Allergy Network, 30).

If an allergen is detected following product distribution, product recalls may be necessary. Doing things right the first time is a more sensible alternative. Data for the first few months of a recent year reveal 79 food product recalls, with 21 related to allergens (FDA, 31). Either an independent lab or allergen test kits may authenticate that products are allergen-free. Testing is part of industry's good manufacturing practices (GMPs).

According to the Director of the Office of Scientific Analysis and Support at FDA's Center for Food Safety and Applied Nutrition "... both FDA and food companies are looking harder for allergens ... allergic consumers are becoming more aware of the allergens in foods, and ... [there are] improved allergen-detection methods"

Some of the best practices for allergen control relate to the following:

- R&D/product development
- Engineering and system design with dedicated production lines
- Vendor certification of raw materials and ingredients
- Production scheduling to include longer production runs
- Rework segregated
- Labeling and packaging with the right product going into the right package, and ingredients listing to match the actual food product
- Sanitation: a HACCP-like approach
- Training (32)

RESPONSIBILITY FOR FOOD SAFETY

There are increasing numbers of "at-risk" populations that complicate the prevention of foodborne and waterborne illnesses, but the food supply should be safe. Governments, food companies, food service establishments, and consumers each are responsible for safe food. Recently food safety experts ranked food handling behaviors that were appropriate for food safety and preventing foodborne illnesses from pathogens, *including Listeria monocytogenes, Salmonella enteriditis, Escherichia coli 0157:H7, Bacillus cereus, Clostridium perfringens, Staphylococcus, and Shigella ssp*. (33)). Food handling behaviors of sticking to the basics is encouraged. (29)

Governments around the world regulate their own food supply (Chapter 20) to assure its safety and wholesomeness, by fostering science-based regulation, inspection and enforcement services, education, and research. In the United States, the FDA and the USDA's FSIS have a history of providing their numerous, well-researched documents (also available on their websites) on foodborne illness and risk assessment to both the food manufacturer and consumer.

The *USDA* continues to collaborate with states and private companies to protect food. "Food safety remains top priority at USDA." (USDA Homeland Security) Food defense exercises are taking place throughout the United States to coordinate government, non-government, and the private sector alike. The strategic Partnership Program Agroterrorism (SPPA) initiative was conducted by the USDA's Farm Service Agency and Grain Inspection, Packers, and Stockyards Administration in cooperation with the FDA in 2005.

The Food and Drug Center for Food Safety and Applied Nutrition cites seven critical hindrances to maintaining a sanitary operation. These areas include the aforementioned microorganisms: bacteria and mold, chemical contamination, pests, including birds, insects, and rodents, as well as ignorance/carelessness. Thus, targeted employee training in these critical areas is crucial to food safety.

In the food *industry*, a loss of human life, loss of brand loyalty, or loss of the company itself may propel personnel to maintain the right attitude and do things right. Crisis management teams and crisis management plans must emphasize prevention.

Food manufacturing and processing industries, as well as food service operations, including hospitals, nursing homes, and restaurants, must comply with government regulations. For example, as a means of food protection, foods companies have reevaluated strategies to provide required plant sanitation and prevent product recalls. (A discussion of the potential for recalls for processors, including a 12-point risk reduction checklist, is presented in Food Engineering, October 1998.) Increases in both time and financial resources allocated to food safety are apparent, as is the hiring of plant design engineers trained in sanitation (34).

Food processors including slaughterhouses are subject to close scrutiny from the FSIS so that there is no risk of mad cow disease in the nation's meat supply. Inspectors continually receive audits and training to ensure safety. Food safety websites provide the latest in food safety news, recall information consumer advice, instructions on reporting possible foodborne illnesses, and more (www.foodsafety.gov/presidentscouncil).

As the president of a food safety and sanitation consulting firm noted, "Sanitation is an attitude, not a process." "The bulk of sanitation cannot be done during production, that's the way the rule is and that's not going to change" (34). Also, food companies may literally move "sanitation" tasks from the third shift to the first or second shift, reflecting different priorities and the adoption of a greater emphasis on sanitation and the safety of their food products. Perhaps it is insufficient to just say that a food is safe. Data must support the claim.

In a recent article entitled "Why can't scientists communicate science?—poor media coverage and a lack of consumer education feed fear about our nations food supply" an important question was raised. It asks "..how can an industry that can produce such bounty have a problem when it comes to communicating safety and efficiency?" Perhaps safety is not sensational enough for some media reporters. Yet, there might not be anything wrong with "touting your own success" or "blowing your own horn" to tell the public how good things are in science and technology and food safety. "Our food supply is potentially the healthiest in the world. We should tell people how we do it" (1)

*Consumer*s ultimately must be responsible for the consumption of safe foods that they themselves prepare or that are processed/prepared by others in the food supply. The consumer must be vigilant and become educated on matters concerning food safety because it may be literally in the hands of the food handler!

The large body of food and nutrition professionals, represented by the American Dietetic Association (ADA), has stated the following:

> "It is the position of the American Dietetic Association that the public has the right to a safe food and water supply. The Association supports collaboration among dietetics professionals, academics, and representatives of the food industry and appropriate government agencies to ensure the safety of the food and water

> supply by providing education to the public and industry, promoting technological innovation and applications, and supporting further research"

Responsibility is broadened when the food *environment* is considered. For example, in addition to food temperatures, health department "floors, walls, and ceilings" issues must be addressed. An antimicrobial floor coating can protect against bacterial or mold growth in food processing plants.

RECALLS

It may be seen that responsibility for food safety is the "work of many". Yet, despite the increased attention to, and demand for food safety at supermarkets and restaurants, food recalls have become too numerous in recent years. Contaminated food had to be removed from the store shelves, and unfortunately, some was removed "after the fact" when those (man and animals) who consumed the unsafe food became ill or even tragically died. The costs in health run high, and recalls are expensive in dollars too.

One industry group, The Almond Board of California, which produces over one billion pounds of almonds annually, suffered two Salmonella outbreaks in recent years. Now, growers have voluntarily adopted Good Agricultural Practice (GAP's) and developed a nw 7 step guide. This program includes documentation, employee training, fertilizer and soil amendment practices, water quality and sourcing, orchard floor management, field sanitation, pest control and employee hygiene.

BIOTERRORISM THREAT TO FOOD SAFETY

Responsibility for food safety has been discussed. Specifically, agencies related to food safety and emergency preparedness are: American Red Cross, CDC, FEMA, FDA, OSHA, USDA, and state and local agencies. Several agency reports are cited below. Needless to say the agencies are no replacement for personal vigilance.

The **Bioterrorism** Preparedness and Response **Act** of 2002 ("the **Bioterrorism Act**") was issued and contained the following:

> "The events of Sept. 11, 2001, reinforced the need to enhance the security of the United States. Congress responded by passing the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (the Bioterrorism Act), which President Bush signed into law June 12, 2002. http://www.fda.gov/oc/bioterrorism/bioact.html

The Bioterrorism Act is divided into five titles:

- Introduction
- Title I—National Preparedness for Bioterrorism and Other Public Health Emergencies

- Title II—Enhancing Controls on Dangerous Biological Agents and Toxins
- Title III—Protecting Safety and Security of Food and Drug Supply
- Title IV—Drinking Water Security and Safety
- Title V—Additional Provisions

The FDA is responsible for carrying out certain provisions of the Bioterrorism Act, particularly Title III, Subtitle A (Protection of Food Supply) and Subtitle B (Protection of Drug Supply).

In the interim final rule reported on September 28, 2005, registration of food facilities is required. The rule requires domestic and foreign facilities that manufacture, process, pack, or hold food for consumption in the United States to register with FDA. Final rule:

- http://www.fda.gov/bbs/topics/news/2005/new01236.html.

The FDA answers some consumer questions on issues of food safety and terrorism, such as on 9/11/01. The discussion appears in the following website.

- www.cfsan.fda.gov/~dms/fsterrqa.html

The USDA also is charged with the duty of protecting the nation's food supply from terrorist threats. Dr. Richard Raymond, USDA Undersecretary for food safety, states "We remain steadfast in our commitment to work with our federal, state and private sector partners so that we can keep or agricultural commodities safe."

> "The U.S. Department of Agriculture's Food Safety and Inspection Service (FSIS) celebrated 100 years of protecting consumers, "As we stand on the threshold of the second century of ensuring the safety of America's meat, poultry and egg products, we take pride in our achievements in public health protection and look forward to strengthening our commitment to safeguarding future generations"
>
> The USDA has said:
>
> - *"Forming the USDA's Homeland Security Council was the first step in a series of organizational changes aimed at improving the Department's ability to perform homeland security- related activities"* (**former Secretary Ann M. Veneman**, *Statement —Sept. 9, 2003).*

An interesting USDA article entitled "Keeping Food Safe during an Emergency" may be seen at the following address:

- http://www.fsis.usda.gov/fact_sheets/keeping_food_safe_during_an_emergency/index.asp (Keeping Food Safe during an Emergency)

The CDC includes

- http://www.bt.cdc.gov/agent/agentlist-category.asp

For various biologic agents, causes, systems affected, routes of transmission and stages of clinical presentation. Also in Spanish. Locate agents alphabetically A–Z or by category A, B, C:

- http://www.cdc.gov/mmwr/preview/mmwrhtml/rr4904a1.htm

The International Foodservice Distributors Association (IFDA) has the following to say regarding vigilance and food safety since September 11 attacks:

> "The intent of those who store and deliver food for foodservice operations is to prevent or minimize the potential for attacks on the food supply. Their aim is to have a safe and secure system. Each individual program should be equipped to minimize threats 'to the greatest extent possible' (35).

For *food service operations* deliveries and **memorandum of understanding (MOUs)"** are significant. They greatly assist in emergencies.

"MOUs are . . . written agreements are used to specify what is transported, when, to where, and so forth. Foodservice Distributors serving the healthcare industry and/or others may provide arrangements for the provision of food and food related products (including bottled drinking water)."

Another reference for bioterrorism threats and food safety is two bioterrorism training computer modules (UTHSCSA) related to food safety. The modules contain the following information: "If/when disasters and emergencies happen, the foodservice operation must be prepared. As best as possible, all contamination should be prevented; the foods should be comforting, aligned with culture, ethnicity, religion, nutrition and so forth. Everyday practice of precautions, or 'the right way' to do something in a non-emergency situation, lessens any panic in an emergency!" (36)

"The professionals agree that even the best-laid plans and training will not address all situations. The key factor in addressing unexpected situations is to maintain a calm demeanor; make decisions, whether they are right or wrong; and be flexible in changing the decisions that do not work" (37)

"Safety considerations

- In a workplace that is equipped for emergency preparedness, there must be a constant check and consideration for safety.
- Safety may be threatened by accidental and intentional activities.
- *In-house* regulation by Safety Committee or an *outside* agency contributes to the regulation of safety in the foodservice.
- Intentional bioterrorist attack may introduce foreign objects into the workplace.
- Questionable chemicals should not be used or handled, and suspect persons or packages should be reported" (36).

"Mildred M. Cody, PhD, RD, author of the American Dietetics Association's *Food Safety for Professionals*, agrees that adhering to basic food safety behaviors will help reduce the risk of foodborne illnesses. However, considering the fact that a bioterrorism attack would be silent and the effects might not be visible for several days, Cody also emphasizes following these additional standard food safety guidelines on a day-by-day basis (38):

Some relevant food science facts appear below:

Terrorism and Food Science
Relevant Food Science Facts

Government Agencies Protecting the Food Supply

- Emergency preparedness has been increased following 9/11.
- Students in nutrition, dietetics (RD), food science, and culinary arts are expected to "expect the unexpected" and follow all rules and regulations and current information of governmental agencies such FDA, USDA, FEMA, CDC, and health departments.

Food Processing

- Processors, both consumers at home and corporations, must protect foodstuffs that they are processing.
- Foods are protected against hazardous external conditions by canning, etc.

Food Safety and Spoilage

- Foods may become contaminated by hazards including biological, chemical or physical. Prevention of hazards is a key to food safety.
- Microbiological hazards include bacteria, viruses, fungi, and parasites.
- Specific bacteria are listed in the CDC web site.
- Control measures for bacterial hazards; includes proper temperatures for storage, cooking and holding with avoidance of the TDZ, eliminating all cross-contamination; practice meticulous personal hygiene.
- Chemical hazards include intentional and unintentional substances, and may be accidental, additives, toxic metals, or toxic substances.
- Physical hazards are foreign objects in food. They may harm health, cause psychological trauma or dissatisfaction, and must not be viewed merely as a manufacturing inconvenience. (36)

FEMA's shelf life of foods for storage appears below:

Shelf Life of Foods for Storage (FEMA)

General guidelines for rotating common emergency foods.

Use within *six months*:

- Powdered milk (boxed)
- Dried fruit (in metal container)
- Dry, crisp crackers (in metal container)
- Potatoes

Use within *one year*:

- Canned condensed meat and vegetable soups
- Canned fruits, fruit juices and vegetables
- Ready-to-eat cereals and uncooked instant cereals (in metal containers)
- Peanut butter
- Jelly
- Hard candy, chocolate bars and canned nuts

May be stored *indefinitely* (in proper containers and conditions):

- Wheat
- Vegetable oils
- Corn
- Baking powder
- Soybeans
- Instant coffee, tea
- cocoa
- Salt
- Noncarbonated soft drinks
- White rice
- Bouillon products
- Dry pasta
- Powdered milk (in nitrogen-packed cans)

- Accept only food from reputable vendors to take advantage of public controls from regulatory agencies
- Check for intact packaging. Wash cans before opening to keep debris from can lids from falling into foods."

"In the case of water for drinking, cooking or cleaning, it is essential that it is safe. Some FEMA suggestions for purified water follow; however, there may still be some dangerous chemical or physical residue.

- Boiling . . .
- Chlorination uses liquid chlorine bleach (5.25% sodium hypochlorite as the only ingredient) to kill microorganisms . . .
- Purification tablets release chlorine or iodine . . .

"In addition to provisions for the *work environment*, Cody advises *individuals* to keep three days or more worth of food, water [One gallon of water (drinking) per person per day] and prescription medicine available, because while safe food and water will be made available after a bioterrorism emergency, the distribution of these items may take some time to coordinate and organize."

"As reported by Puckett and Norton, ideas for training within the disaster plan of a food service operation include:

- Review of plans and employee duties before, during, and after an emergency
- Security procedures
- Location of water, food, emergency supplies, first aid supplies, fire fighting equipment, water purification system, and key employees
- Safe food handling
- Sanitizing procedures
- Record keeping
- Physical layout of the food service area and entire facility
- Physical security
- ID badges
- Important names and numbers, including vendor data" (37).

For More Information

- Congressional Inquiries: (202) 720-3897
- Constituent Inquiries: (202) 720-8594
- USDA Meat and Poultry Hotline: (800) 535-4555 or (202) 720-3333
- Consumer Inquiries: Call USDA's Meat and Poultry Hotline at 1-800-535-4555.

In the Washington, DC, area, call (202) 720-3333. The TTY number is 1-800-256-7072.

Emergency Point of Contact

US Food and Drug Administration 5600 Fishers Lane Rockville, MD 20857

If a food establishment operator suspects that any of his/her products that are regulated by the FDA have been subject to tampering or criminal or terrorist action, he/she should notify the FDA 24-hour emergency number at 301-443-1240 or call their local FDA District Office. FDA District Office telephone numbers are listed at http://www.fda.gov/ora/inspect_ref/iom/iomoradir.html. The operator also should notify local law enforcement.

CONCLUSION

The consumer expects safe food and protection from microbial, chemical, and physical hazards to the food supply. Foodborne illness may originate from bacteria, viruses, mold, parasites, and naturally occurring chemicals in food (such as toxins), accidental chemical contamination, toxic levels of additives or preservatives, and foreign objects. It may severely impact the health and welfare of a food company, hospital, restaurant, or the consumer at home.

The HACCP is a food safety system that focuses on foodborne disease prevention and ensures a greater likelihood of food safety. Various segments of the food industry apply the HACCP system of food protection to their handling of hazardous ingredients. HACCP team members promote food safety by assessing potential hazards in the flow of foods through their operation and by establishing limits or controls for the identified hazards. HACCP is applied to all steps of handling, including processing, packaging, and distribution. This same process may be followed by foodservice operations.

The CDC monitors and reports FBDOs. Open and code dating are utilized. Food allergens are monitored by the FDA. It is the consumer (the one who consumes!) who must ultimately be responsible for the consumption of safe foods. The USDA Food Safety Research Information Office (FSRIO) has created a new web site for the general public and food safety researchers. The site contains educational, professional, and foreign government links for food safety: www.nal.usda.gov/fsrio.

GLOSSARY

Biological hazard: Microbiological hazard from bacteria, viruses, fungi, and parasites.

Chemical hazard: Toxic levels of a specific chemical that may occur by accident, use of toxic levels additives, or toxic metals.

Contaminated: Presence of harmful substances.

Cross-contamination: Transfer of harmful microorganisms from one food to another by way of another food, hands, equipment, or utensils.

Emerging pathogens: Pathogens whose incidence has increased within the last few years or which threaten to increase in the near future.

Foodborne illness: Disease carried to people by food.

Fungi: Microorganisms that include mold and yeast.

HACCP: Hazard analysis and critical control point system of food safety.

Infection: Illness that results from ingesting living, pathogenic bacteria such as *Salmonella*, *Listeria*, or *Shigella*.

Intoxication: Illness that results from ingesting a preformed toxin such as that produced by *Staphylococcus aureus*, *Clostridium botulinum*, or *Bacillus cereus*.

Pathogenic: Disease-causing agent.

Physical hazard: Foreign object found in food; may be due to harvesting or manufacturing; may be intrinsic to the food (bone, shell, pit).

Potentially hazardous food: Natural or synthetic food in a form capable of supporting the rapid and progressive growth of infectious or toxigenic microorganisms; the growth and toxin production of *C. botulinum*, or in shell eggs, the growth of *S. enteritidis*.

Spoiled: Damage to the eating quality.

Spore: Thick-walled formation in a bacterium that is resistant to heat, cold, and chemicals; it remains in food after the vegetative cells are destroyed and is capable of becoming a vegetative cell.

Temperature danger zone (TDZ): Temperature range within which most bacteria grow and reproduce 40–140 °F (4–60 °C).

Toxin: Poison produced by a microorganism while it is alive; may remain in food and cause illness after the bacteria is killed.

Toxin-mediated infection: Infection/intoxication illness that results from ingestion of living, infection-causing bacteria that also produce a toxin in the intestine, such as *C. perfringens* or *E. coli* 0157:H7.

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Silliker Laboratories Group Inc., Educational Services Group, Homewood, IL.

Texas A&M University—Center for Food Safety, College Station, TX.

ASSOCIATIONS AND ORGANIZATIONS

The American Dietetic Association (ADA) National Center for Nutrition and Dietetics (NCND), Chicago, IL

American Public Health Association (APHA), Washington, DC

Association of Food and Drug Officials (AFDO), York, PA

Cooperative Extension Service (CES), throughout the United States

Council for Agriculture Science and Technology (CAST), Ames, IA

Food Marketing Institute (FMI), Washington, DC

Institute of Food Technologists (IFT), Chicago, IL

International Association of Milk, Food, and Environmental Sanitarians (IAMFES), Des Moines, IA

International Food Manufacturers Association (IFMA), Chicago, IL

International Council of Hotel and Restaurant Industry Educators (CHRIE), Washington, DC

National Environmental Health Association (NEHA), Denver, CO

National Sanitation Foundation (NSF) International, Ann Arbor, MI

The Educational Foundation of the National Restaurant Association (NRA), Chicago, IL

United States Environmental Protection Agency, (EPA), Washington, DC

Associations referenced in the text:

National Center for Nutrition and Dietetics (NCND)

Cooperative Extension Service (CES)

Council for Agriculture Science and Technology (CAST)

The Educational Foundation of the National Restaurant Association (NRA)

Note – Referenced websites may be subject to change and may not remain available.

CHAPTER 17

Food Preservation and Processing

INTRODUCTION

Preservation by heat, cold refrigeration, freezing temperature, or other means and application of the preservation techniques are introduced in this chapter. Storage conditions and preservation processes are subject to Food and Drug Administration (FDA) inspection and enforcement. Preservation from microbial, chemical, and physical contamination, as well as enzymatic activity, is necessary for preserving and extending the shelf life (the time a product can be stored without significant change in quality) of food. Adequate packaging is important in preserving food (Chapter 19). Preservation and processing of foods make food last, look good, and taste good.

HEAT PRESERVATION

Heating or cooking foods as a means of preserving them or making them more palatable has been important for centuries. Heating is a vital form of food preservation and there are many different methods of heating processes available today.

Foods are heat processed for four main reasons:

- To eliminate pathogens (organisms that cause disease)
- To eliminate or reduce spoilage organisms
- To extend the shelf life of the food
- To improve palatability of the food

Methods of Heat Transfer

Heat may be transferred to a food by conduction, convection, or radiation. The following listing offers a brief discussion of each:

Conduction is the term used for the transfer of heat from molecule to molecule and is the major method of transfer through a solid. Examples of heat transfer by conduction include a saucepan resting on a hot ring. The heat is transferred by direct contact with the heat source. This is a relatively slow method of heat transfer.

Convection occurs when currents are set up in heated liquid or gas. For example, as water is heated in a saucepan, the warmer sections become less dense and therefore rise, whereas the cooler regions flow down toward the bottom of the pan. This sets up a flow or current, which helps to spread the heat throughout the liquid. Heating by convection therefore is faster than heating by conduction.

Radiation is the fastest method of heat transfer. This occurs when heat is transferred directly from a radiant heat source, such as a broiler or a campfire, to the food to be heated. The energy is transferred in the form of electromagnetic waves. Any surfaces between the heat source and the food being heated reduce the amount of energy transmitted by radiation. The rays fan out as they travel and so the farther a food is from the heat source, the fewer rays it receives and the longer it takes to get hot.

Heat Treatment Methods

Heat treatment methods can be divided into two categories, depending on the amount of heat applied: The heat processing method may be *mild* or *severe*. The aims, advantages, and disadvantages of these two types of heat treatment are different. Depending on the objectives, a food processor may choose to use either a mild or a severe form of heat treatment to preserve a food product. Consumers rely on cooking to uphold conditions of food safety in the home. The two types of heat treatment will be discussed in detail; an overview of the main aims, advantages, and disadvantages of both is shown in Table 17.1.

Mild Heat Treatment. Examples of *mild* heat treatment include pasteurization and blanching.

Pasteurization is a *mild* heat treatment used for milk, liquid egg, fruit juices, and beer. The main purpose of pasteurization is to achieve the following:

- Destroy pathogens
- Reduce bacterial count
- Inactivate enzymes
- Extend shelf life

Pathogens are microorganisms causing foodborne disease, either directly (foodborne infection) by releasing a substance that is toxic (foodborne intoxication), or via a toxin-mediated infection. All pathogens must be destroyed so that the food is safe to eat or drink; however, a pasteurized product is *not* sterile, the bacterial count in a pasteurized product is simply reduced. Any bacteria that are more heat resistant than those pathogens intended for destruction will not be destroyed and they are able to grow and multiply in the food. They will cause

Table 17.1 Overview of Mild and Severe Heat Treatments

Mild Heat Treatment	Severe Heat Treatment[a]
Aims	*Aims*
Kill pathogens	Kill *all* bacteria
Reduce bacterial count (food is *not* sterile)	Food will be commercially sterile
Inactivate enzymes	
Advantages	*Advantages*
Minimal damage to flavor, texture, and nutritional quality	Long shelf life
	No other preservation method is necessary
Disadvantages	*Disadvantages*
Short shelf life	Food is overcooked
Another preservation method must be used, such as refrigeration or freezing	Major changes in texture, flavor, and nutritional quality
Examples	*Examples*
Pasteurization, blanching	Canning

[a] See the section on canning.

spoilage of the food after a while, but that is usually obvious, as opposed to the unseen proliferation of pathogens causing contamination.

To increase the shelf life of a pasteurized product, it is necessary to refrigerate it to delay bacterial growth. For example, milk is pasteurized to ensure that it is safe to drink, but harmless bacteria are still present. If the milk is kept out on the kitchen counter on a warm day, the bacteria grow and produce lactic acid and the milk turns sour within a day or two. However, milk can be stored in a refrigerator for at least a week and sometimes longer before it turns sour.

The mild heat treatment involved in pasteurization usually is sufficient to denature and inactivate enzymes. For example, milk contains the enzymes phosphatase and lipase, both of which are denatured during pasteurization (Chapter 11). To ensure that milk has been pasteurized properly, a colorimetric phosphatase test may be performed: if phosphatase is present, it turns a chemical reagent blue, indicating that the heat treatment has been insufficient. Absence of the blue color indicates that the phosphatase has been inactivated and the milk has been adequately pasteurized.

For detailed description of pasteurization of milk, see Chapter 11. Pasteurization of other products may differ in detail, but the principles are the same. For example, egg white or whole egg are heated to 140–144°F (60–62°C) and held for 3.5–4.0 minutes to prevent growth of *Salmonella*. Fruit juices also are pasteurized, the main aim being to reduce the bacterial count and to inactivate enzymes, as fruit juices do not *normally* carry pathogenic microorganisms.

Blanching is another *mild* heat treatment, used mainly for vegetables and some fruits prior to freezing. The main aim of blanching is to *inactivate enzymes* that would cause deterioration of food during frozen storage. This is essential, because freezing does not completely stop enzyme action and so foods that are stored in the frozen state for many months slowly develop off-flavors and off-colors.

Blanching usually involves dipping the vegetable in boiling or near-boiling water for 1–3 minutes. Blanching treatments have to be established on an experimental basis, depending on size and shape and enzyme level of the different vegetables. For example, peas, which are very small, require only 1–1.5 minutes in water at 212°F (100°C), whereas, cauliflower or broccoli that are broken into small flowerets require 2–3 minutes. Corn on the cob is blanched for 7–11 minutes depending on size to destroy the enzymes within the cob itself.

Some destruction of bacteria also is achieved during blanching and the extent depends on the length or the heat treatment. As with pasteurization, blanching does not produce a sterile product. Foods that have been blanched require a further preservation treatment to significantly increase their shelf life. Usually foods are frozen after blanching.

Canning: Severe Heat Treatment. Canning is a well-known method employed in food preservation. It involves hermetically sealing food in a container, and then inhibiting pathogenic and spoilage organisms with the application of heat. Nicholas Appert (1752–1841) is credited with the thermal process of canning, which was discovered (1809) as a result of a need to feed Napoleon's troops. One year later Peter Durand received a patent for the tin-plated can. Decades later, Louis Pasteur understood the principle of microbial destruction and was able to provide the explanation for canning as a means of preservation. Samuel Prescott and William Underwood in the United States established further scientific applications for canning, including time and temperature interactions, in the late 19th century (for more information on canning, see Chapters 7 and 19).

Canning (Table 17.1) is an example of a food processing method that involves *severe* heat treatment. Food is placed inside a cylinder or body of a can, the lid is sealed in place, and the can is then heated in a large commercial pressure cooker known as a retort. Heating times and temperatures vary, but the heat treatment must be sufficient to sterilize the food (1). Temperatures in the range 241 to 250°F (116–121°C) are commonly used for canning. Calcium may be added to canned foods as it increases tissue firmness.

The main purpose of canning is to achieve the following:

- Commercial sterility
- Extended shelf life (more than 6 months)

Commercial sterility is defined as "that degree of sterilization at which all pathogenic and toxin-forming organisms have been destroyed, as well as all other types of organisms, which if present could grow in the product and produce spoilage under normal handling and storage conditions." Commercially sterilized foods may contain a small number of heat-resistant bacterial spores that are unable to grow under normal conditions. However, if they were isolated from the food and given special environmental conditions, they could be shown to be alive (2).

Most commercially sterile foods have a shelf life of 2 years or more. Any deterioration that occurs over time is due to texture or flavor changes, not due to microbial growth.

In the case of canning fruits and vegetables, the canneries may be located immediately near the field. The raw food is washed and prepared, blanched, placed into containers, perhaps under a vacuum (to mechanically exhaust the air), sealed, sterilized to destroy remaining bacteria, molds, yeasts [240 °F (116 °C)], then cooled, and labeled. Next, the can is sent to the warehouse for storage prior to distribution.

The Effect of Heat on Microorganisms

Heat denatures proteins, destroys enzyme activity, and therefore kills microorganisms. Bacteria are destroyed at a rate proportional to the number present in the food. This is known as the *logarithmic death rate*, which means that at a constant temperature, the same percentage of a bacterial population will be destroyed in a given time interval, irrespective of the size of the surviving population (Table 17.2). In other words, if 90% of the bacterial population is destroyed in the first minute of heating, then 90% of the remaining population will be destroyed in the second minute of heating, and so on. For example, if a food contains 1 million (10^6) organisms and 90% are destroyed in the first minute, then 100,000 (10^5) organisms will survive. At the end of the second minute, 90% of the surviving population will be destroyed, leaving a population of 10,000 (10^4) microorganisms. This is illustrated in more detail in Table 17.2.

TABLE 17.2 Logarithmic Death Rate

Time (min)	No. of survivors
1	1, 000, 000
2	100, 000
3	10, 000
4	1, 000
5	100
6	10
7	1
8	0.1
9	0.01

Note: In this table, the decimal reduction time is 1 minute.

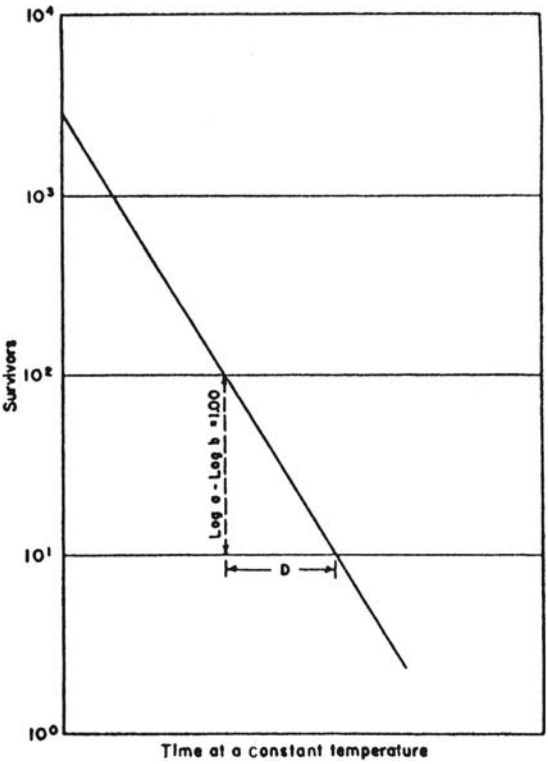

FIGURE 17.1 A typical thermal death–rate curve
(*Source:* Stumbo. *Thermobacteriology in Food Processing*, 2nd ed. Academic Press, NY, 1973).

If the logarithm number of survivors is plotted against the time at a constant temperature, a graph is obtained like the one shown in Figure 17.1. This is known as a ***thermal death rate curve*** (Figure 17.1). Such a graph provides data on the rate of destruction of a specific organism in a specific medium or food at a *specific* temperature.

An important parameter that can be obtained from the thermal death rate curve is the ***D value*** or ***decimal reduction time***. The *D* value is defined as the time in minutes at a specified temperature required to destroy 90% of the organisms in a given population. It also can be described as the time required to reduce the population by a factor of 10, or by one log cycle.

The *D* value varies for different microbial species. Some microorganisms are more heat resistant than others; therefore, more heat is required to destroy them. The *D* value for such organisms will be higher than the *D* value for heat-sensitive bacteria. A higher *D* value indicates greater heat resistance, because it takes longer to destroy 90% of the population.

Destruction of microorganisms is temperature dependent. Bacteria are destroyed more rapidly at higher temperatures; therefore, the *D* value for a particular organism decreases with increasing temperature. For a specific

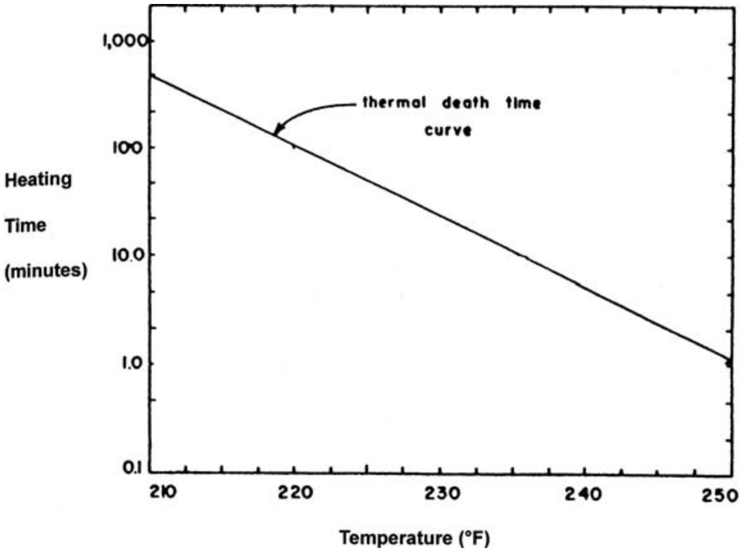

FIGURE 17.2 A typical thermal death–time curve
(*Source*: Adapted from Desrosier and Desrosier. *Technology of Food Preservation*, 4th ed. AVI Publishing Co. Westport, CT, 1977).

microorganism in a specific food, a set of *D* values can be obtained at different temperatures. These can be used to plot a *thermal death time curve* (Figure 17.2) with the logarithm of the time plotted on the *Y* axis and the temperature on the *X* axis.

A thermal death time curve provides data on the destruction of a specific organism at different temperatures. The heating time on the graph may be the *D* value or it may be the time to achieve 12 *D* values, as will be explained later. The important thing to remember about the thermal death time curve is that every point on the graph represents destruction of the same number of bacteria. In other words, every time–temperature combination on the graph is equivalent in terms of killing bacteria. Such graphs are important to the food processor in determining the best time–temperature combination to be used in canning a particular product and ensuring that commercial sterility is achieved.

The other parameters shown on the thermal death time curve are beyond the scope of this book and so will not be explained in detail here. (The *z* value indicates the resistance of a bacterial population to changing temperature and the *F* value is a measure of the capacity of a heat treatment to sterilize.)

Selecting Heat Treatments

All canned food must be commercially sterile, and therefore must receive a heat treatment that is sufficient to kill essentially all bacterial vegetative cells and spores. However, such severe heat treatment adversely affects food qualities such as texture, flavor, and nutritional quality. The food processor aims to ensure commercial sterility, but to achieve this using the mildest heat treatment possible so that the food does not taste too "overcooked." In other words, the optimal heat treatment will do the following:

- Achieve bacterial destruction (commercial sterility)
- Minimize adverse severe heat effects
- Be the mildest heat treatment necessary

To select a safe heat preservation treatment, it is important to know the time–temperature combination required to inactivate the most heat-resistant pathogens and spoilage organisms in a particular food. This depends on several factors:

1. *The heat penetration characteristics of the food.* The food in the center of the can must receive sufficient heat treatment to achieve commercial sterility. This may mean that the food toward the outside of the can is overcooked. How fast the heat penetrates to the center of the can depends on the size of the can and also on the consistency of the food. Heat will reach the center of liquid foods, such as soup, much more quickly than solid foods such as meat.
2. *The pH of the food.* Bacteria are more heat resistant at neutral pH than they are in acid. Therefore, high-acid foods, such as tomatoes or fruits, need a less severe heat treatment to achieve sterility.
3. *The composition of the food.* Proteins, fats, and sugar in high concentrations all have a protective effect on bacteria, because they hinder the penetration of wet heat; thus, a more severe heat treatment is needed to sterilize foods that are high in protein, fat, or sugar.
4. The pathogenic and spoilage organisms likely to be present.

It is important to have thermal death time curve data available for the most heat-resistant microorganisms that may be present in the food. Such data must be obtained for the food to be processed, as the composition of the food affects the heat sensitivity of the bacteria. Thermal death time curves obtained in one food may not apply to the same bacteria in a different medium. Without obtaining thermal death time curves for the specific food, it is impossible to ensure commercial sterility.

As already has been mentioned, every point on the thermal death time curve is equivalent in terms of destruction of bacteria. An increase in temperature greatly reduces the time required to achieve commercial sterility. However, the color, flavor, texture, and nutritional value of foods are not as sensitive to temperature increase. Generally speaking, a 50°F (10°C) rise in temperature *doubles* the rate of chemical reactions but causes a *tenfold* increase in the thermal death rate. Therefore, a high-temperature short-time combination is preferred, in order to minimize adverse chemical changes in the food such as loss of flavor, texture, and nutritional quality. The food processor wants to use the time–temperature combination that causes the least damage to food quality.

REFRIGERATION PRESERVATION

Our ancestors were familiar with placing food in cold cellars, holes in the ground, or natural caves, as these storage sites would assure uniform temperatures in storage and preserve food. Ice became widespread as a means of cold preservation in the middle 1800s—food was stored in a closed, wooden "ice box" that contained a block of ice in a chamber above the food to keep it cold. *Mechanical* refrigeration was introduced in the later 1800s and has undergone enormous developments since then.

Refrigerator and freezer temperatures both fail to sterilize food, but the latter temperatures are more effective in retarding bacterial growth. Refrigerated food generally is held at temperatures below 45°F (7.2°C) [41°F (5°C)] and is subject to *state* or *local* FDA or USDA requirements for handling, storage, and transport (3).

The microbiological and safety quality of extended shelf life refrigerated foods continues to be an issue for processors and the food preparer (4). A food may be better preserved in storage if it is stored under controlled atmospheric (CA) conditions. CA extends shelf life by reducing oxygen and increasing carbon dioxide in the atmosphere surrounding fruits (Chapter 7). Controlling gases in the atmosphere also is useful in providing longer storage of meats (Chapter 9) and eggs (Chapter 10). Meat preservation, for example, involves controlling microbial growth, retarding enzymes, and preventing the development of rancidity through the oxidation of fatty acids.

Packaging materials may be used in conjunction with refrigeration to preserve foods (Chapter 19). Simply covering a food inhibits unwanted dehydration and contamination, yet choice of film material used also assists in prolonging shelf life.

Problems Associated with Refrigeration

- **Spoilage**. This is damage to the edible quality of food, is possible without maintenance of the proper temperatures and humidity, use of FIFO, and regular cleaning.
- **Cross-contamination**. This is the transfer of harmful substances from one product to another and is possible without adequate covering or placement of foods. Pathogens from an improperly placed raw product may contaminate other food.
- **Temperatures**. If temperatures are *too cold*, "chill injury" to fresh vegetables or fruits or sugar development in potatoes may result. Low-temperature storage increases the starch content of sweet corn (Chapter 7). *High* refrigerator temperatures or large containers of food that cannot cool quickly can lead to foodborne illness. Potentially hazardous foods must be kept at 41°F (5°C) or less, and if refrigerated after preparation, must be cooled to 41°F (5°C) or less in 4 hours or less. The Centers for Disease Control and Prevention (CDC) report that improper cooling (including improper cooling in the refrigerator)

is by far the number one cause of bacterial growth leading to foodborne illness (see local jurisdiction).

- **Odor**. Odors may be transferred from some foods, such as onions to butter, chocolates, and milk. If possible, strong odor foods should be stored separately from other foods. Packaging may be utilized to minimize odor problems.

FREEZING

Frozen food is held at colder temperatures than refrigeration. As opposed to refrigerator short-term storage, freezing is a long-term storage form that entails several months or a year. In freezing, water is unavailable for bacteria, thus they are dormant and there is no multiplication of pathogens. Foods freeze as their water component turns to ice, or *crystallizes*.

With a *slow* freeze, *extra*cellular crystallization occurs prior to *intra*cellular crystallization; therefore, water is drawn from the inside of the cell as the external solute concentration increases. The result is that cell walls tear and shrink. At a cellular level, there is physical damage to the food as the water expands and the extracellular ice crystallization separates cells. Tissues survive a *rapid* freeze better than a slow freeze because water does not have time to migrate to seed-crystals and form large crystals.

Freezing Methods

Rapid freezing by commercial freezing methods includes the following procedures:

- Air blast tunnel freezing
- Plate freezing
- Cryogenic freezing

Air blast procedures utilize convection and cold air (Figure 17.3). With this method of freezing, foods are placed either on racks that subsequently are wheeled into an insulated tunnel or on a conveyor belt where very cold air is blown over the food at a quick speed. When *all* parts of the food reach a temperature of 0°F (−17.8°C), the packages are put into freezer storage. The products may be packaged prior to or following freezing.

In *plate freezing*, the packaged food is placed between metal plates, which make full contact with the product and conduct cold, so that all parts of the food are brought to 0°F (−17.8°C). Automatic, continuous operating plate freezers can freeze the food and immediately deposit it to areas for casing and storage.

Cryogenic freezing may involve either *immersion* or *spraying* the food product with liquid nitrogen (LIN). LIN has a boiling point of −320°F (−196°C) and therefore freezes food more rapidly than other mechanical techniques. Food such as meats, poultry, seafood, fruits, and vegetables, prepared or processed foods, may be preserved by cryogenic freezing (Figures 17.4 and 17.5). Cryogenic

FIGURE 17.3 MAP system for ready to eat salads in a tray. (*Source:* photograph courtesy of Air Products and Chemicals. Inc).

FIGURE 17.4 Examples of cryogenic freezing of foods (*Source: 8 1996* Air Products and Chemicals, Inc.; photograph courtesy of Air Products and Chemicals, Inc).

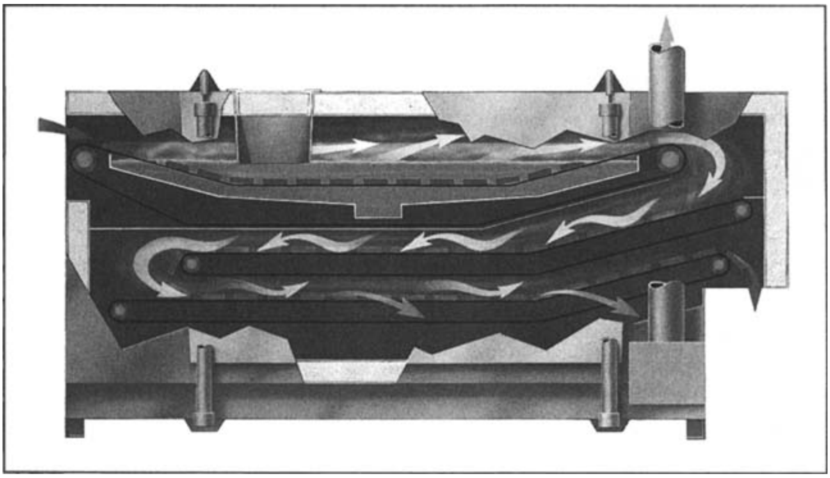

FIGURE 17.5 Example of the cryogenic immersion freezing process (*Source:* Air Products and Chemicals, Inc.; photograph courtesy of Air Products and Chemicals, Inc).

techniques for freezing include use of tunnel freezers that use LIN sprayed onto food. The LIN vaporizes to nitrogen gas at −320°F (−196°C) at the end of the tunnel and then is re-circulated to the tunnel entrance. LIN is approved by the FDA's Food Safety and Inspection Service (FSIS) for contact and freezing both meat and meat products and poultry and poultry products. At home, the consumer does not have these options and it is recommended that no more than 2–3 pounds of food per cubic foot of food be placed in the freezer at one time.

Problems Associated with Freezing

Most of the problems associated with freezing are due to the following:

- *Physical damage* due to formation of ice crystals
- Changes in texture and flavor caused by the *increased solute concentration* that occurs progressively as liquid water is removed in the form of ice.

Both of these effects are minimized by fast freezing methods. Fast freezing minimizes formation of large crystals that would cause the most damage to cell structure and colloidal systems. Ice crystals actually can rupture cell walls, break emulsions, and cause syneresis in gels.

Increases in solute concentration can cause changes in pH, denaturation of proteins, and increased enzyme activity, all of which may lead to deterioration of food quality. Fast freezing shortens the time period during which the concentration effects are important, thereby decreasing their effect on food quality.

Recrystallization may be a problem in maintaining a high-quality product. With refreezing, ice crystals enlarge because they are subject to fluctuating temperatures. Evidence of refreezing frequently is observed with large crystalline formation on the inside of the package.

Freezer burn is the dehydration that may accompany the freezing process. The surface of food may show white patches and become tough. This occurs due to sublimation of ice. Solid ice will become a moisture vapor, bypassing the liquid phase, and the vapor pressure differential between the food material and the atmosphere will lead to sublimation and desiccation. The use of moisture-proof freezer wraps is suggested for storage (Chapter 19).

Oxidation may lead to the development of off-flavor fats, as the double bonds of unsaturated fats are oxidized. Fruits and vegetables may brown due to enzymatic oxidative browning if enzymes are not denatured before freezing. Vitamin C (ascorbic acid) may be oxidized.

Colloidal substance change in freezing may occur due to the following:

- Starch syneresis—the freezing and thawing cycle may produce "weeping" because in thawing, less water is reabsorbed than what was originally present (Chapter 4).
- Cellulose—becomes tougher.
- Emulsions—break down, are subject to dehydration and precipitation.

Chemical Changes to Frozen Foods

Chemical changes to foods may occur as they are frozen. Off-odors may develop as acetaldehyde is changed to ethanol. As mentioned earlier, in oxidation, enzymatic oxidative browning is observable as phenols react with available oxygen and ascorbic acid may become oxidized. It is recommended that blanching occur prior to freezing, as it may prevent oxidation. Pigments such as chlorophyll undergo degradation.

Eggs show an increased concentration of soluble salts in unfrozen portions if freezing is slow. Egg yolks show granule disruption due to an aggregation of low-density lipoproteins, forming a gummy product.

Moisture Control in Freezing

Drying occurs when a food gives up water to the atmosphere. Such dehydration also draws water from bacterial cells too, which is needed for subsequent growth outside of the freezer.

Added Sugar and Salt

The addition of salt or sugar lowers the freezing point, rendering water less available for microbial growth.

DEHYDRATION

Dehydration is a means of preservation that subjects food to some degree of water removal. The primary intent is to reduce moisture content and preclude the possibility of microbial growth such as bacteria, mold, and yeast. A decrease in relative humidity (RH) leads to a decrease in microorganism growth.

While traditional methods of drying are utilized around the world, new drying techniques are being developed. Methods used for drying foods include the following:

- Natural or sun drying—dries by direct sunlight or dry, hot air.
- Mechanical drying—dries with heated air blown in a tunnel, cabinet, or tray that contains the food (fluidized-bed drying, where hot air passes through the product and picks up moisture is a special type of hot air drying).
- Drum drying—dries the product on two heated stainless steel drums before it is scraped off. Milk, juices, and purees may be dried in this manner.
- Freeze drying—*freezes* and subsequently *vacuums* to evaporate moisture in the process of sublimation (ice is converted to a vapor without passing through the liquid phase); examples include instant coffee, meats, and vegetables.
- Puff drying—either by *heat* and subsequent *vacuum* (to increase the pressure difference between the internal and external environments) or a combination of vacuuming and steaming. The product also may puff as the temperature of the water in the food is raised above 212°F (100°C) and then external pressure is quickly released. Examples are some ready-to-eat puffed cereal products.
- Smoking—preserves by dehydrating, thus offering microbial control (Chapter 9) and also treats meat to impart flavor by exposure to aromatic smoke.
- Spray drying—dries the product as it is sprayed into a chamber concurrently with hot air. For example, eggs, instant coffee, and milk may be sprayed dried.

The result of dehydration is increased shelf life and a reduction in distribution costs due to less weight.

Deterioration may occur even in dried products. Detrimental color, flavor, or textural changes may result from enzymatic changes, and these may be controlled by deactivating enzymes, by blanching, or adding sulfur compounds prior to dehydrating. Nonenzymatic browning may occur in dried foods either due to caramelization or the Maillard browning. The Maillard reaction products may lead to significant unwelcome browning, development of bitter flavors, less solubility of proteins, as well as diminished nutritive value. Dry milks or eggs and breakfast cereals participate in this reaction. Overall, oxidative spoilage or chemical changes by oxidation of fats is the primary cause of deterioration.

Factors needing control in dehydration include atmospheric conditions such as temperature, humidity, pressure, and portion size. The length of storage time also is a factor in the quality of the end product.

CONCENTRATION

Foods are *concentrated*, primarily to reduce weight and bulk. This makes transportation, shipping, and handling easier and less expensive, and so it is economically advantageous. Many foods are concentrated, including fruit and vegetable juices and purees, milk products, soups, sugar syrups, jams and jellies, to name a few.

Concentration is not usually considered to be a method of preservation of a food, since the water activity is not reduced sufficiently to prevent bacterial growth (see Chapter 2). The exception to this is jams and jellies, which contain high levels of sugar. Additional preservation methods, such as pasteurization, refrigeration, or canning, therefore are used to prevent spoilage of concentrated foods.

Methods of Concentration

Some of the more common methods of concentration are:

- Open kettles—used to concentrate maple syrup, where the high heat produces the desired color and flavor. They also are used for jellies, jams, and some types of soups. The disadvantage of open kettles is the risk of product burn-on at the kettle wall due to high heat and long processing times.
- Flash evaporators—use heated steam (150 °C), which is injected into the food and later removed, along with water vapor from the food. This reduces heating time, but temperatures are still high and so foods may lose volatile flavor constituents.
- Thin-film evaporators—enable the food to be continuously spread in a thin layer on the cylinder wall, which is heated by steam. As the food is concentrated (by removal of water vapor), it is wiped from the wall and collected. Heat damage is minimal due to the short time required to concentrate the food.
- Vacuum evaporators—used to concentrate heat-sensitive foods, which would be damaged by high heat. Operation under vacuum allows concentration to be achieved at much lower temperatures.
- Ultrafiltration and reverse osmosis—expensive processes that may be operated at low temperatures and use selectively permeable membranes to concentrate liquids. Different membranes are required for different liquid foods. These processes are used to concentrate dilute protein dispersions such as whey protein, which cannot be concentrated by traditional methods without being extensively denatured (see Chapter 11). Ultrafiltration involves pumping the dispersion under pressure against a membrane that retains the protein, but allows smaller molecules such as salts and sugars to pass through. Reverse osmosis is similar, but higher pressures are used and the membrane pores are smaller, and so they are able to hold back various salts and sugars as well as larger protein molecules.

Changes during Concentration

The changes that occur during concentration arise primarily due to exposure of food to high heat. A "cooked" flavor may develop and discoloration may occur. In addition, the product may thicken or gel over time, due to denaturation of proteins. This is a potential problem in evaporated milk (Chapter 11). Nutritional quality also may be lost. The extent of the changes depends on the severity of the heat treatment.

Concentration methods that employ low heat or short processing times cause the least damage to food. However, they also are the most costly and may not always be the practical choice for the food processor, who must balance cost against quality.

ADDED PRESERVATIVES

Specific preservatives may be applied to a food to extend shelf life:

- **Acid**—denatures bacterial proteins, preserving food, although not always sufficient to ensure sterility. Acid may be naturally present in foods such as citrus fruits and tomatoes. The combination of acid and heat provides more effective preservation.
- **Sugar and salt**—heavy syrups or brines compete with bacteria for water. By osmosis, the high percentage of water moves out of bacterial cells to equal the lower level of water in the surrounding medium. Other microorganisms, such as the fungi, yeast, and mold, are capable of growing in a high sugar or salt environment. Early US settlers preserved meats using salt and sugar.
- **Smoke**—may contain a preservation chemical such as formaldehyde. Smoke retards bacterial growth due to surface dehydration. Smoking also may be used simply to impart flavor.
- **Chemicals**—subject to FDA approval. The burden of proof for usefulness and harmlessness is on industry. The chemical properties of the foods itself, such as pH and moisture content, affect the growth of microorganisms.

OTHER PRESERVATION TECHNIQUES

In **fermentation**, with the addition of nonpathogenic bacteria to a food, acid is produced, the pH is reduced, and the growth of pathogenic bacteria is controlled.

RADIATION

Foods may be heated by radiant energy including the use of microwave heat treatment or the lesser heat of irradiation.

Microwave Heating

Microwave heating is a nonionizing, rapid method of cooking. It may be used for both processing and preservation. Some commercial uses of industrial microwave that have been considered or put to use include baking, blanching, browning, coagulating, concentrating, cooking, curing, drying, fermenting, freeze drying, gelatinization, heating, pasteurizing, precooking, preservation, processing, proofing, puffing, roasting, separating, shucking, solvent removal, sterilizing, tempering, thawing, and vacuum drying (4)–(8).

It is reported that microwave heating inactivates vitamin B12, which is found in animal products and fortified vegetarian products. The nutrient plays an important role in maintaining the nerve tissue (9).

In combination with newer food packaging technologies, microwaveable foods are plentiful in the marketplace. General recommendations to be followed when heating by microwave include:

- Turn the container while cooking to avoid “hot spots” of concentrated energy in one spot.
- Include a “rest period” or “standing time” beyond the designated cooking time, in order to continue cooking the food.
- Beware of hot containers from conduction of heat from food to the container.
- Select a low power setting for defrosting. Microwave energy is then sent intermittently into the frozen food.

Some definitions relating to the microwave method of heating include the following:

hot spots—the nonuniform heating of high-water foods
molecular friction—the heat generation method of microwave heating
skin—the surface dehydration and hardening as more microwave energy is absorbed at the surface of the food
shielding—protection of portions of food such as cylindrical ends of food, which readily overcook
thermal runaway—differential heating of food without thermal equilibrium

Irradiation

Irradiation is the administration of measured doses of energy that are product-specific. A positive biological effect is that it has a **bactericidal** effect, and thus reduces the microbial load of a food, kills insects, controls ripening, and inhibits the sprouting of some vegetables (10, 11).

Irradiation is a cold process of food preservation that does not add heat to the food. In the spectrum of energy waves, radio waves are at one end of the spectrum, microwaves are in the middle, and the gamma rays of irradiation are at the other end of the continuum. Gamma rays are passed through the food to be irradiated, and the food thus is sterilized and preserved as it passes through an irradiation chamber on a conveyor belt. Scientific evidence demonstrates that foods do not become radioactive and that no radiation residue remains in the food.

Irradiation is a process approved by the Food and Drug Administration for use with specific foods and only at designated dosages. Gamma rays are the isotope-sourced form of irradiation previously mentioned. As well, there is a machine-sourced form of irradiation that is electronically generated. It is known as e-beam (12). Foods that may be irradiated include wheat, potatoes, spices, pork, red meat, fruit, poultry, dehydrated enzymes, or vegetable substances, including fresh produce (and bagged salads). So, in looking at dosages needed for pork, as an example, it is shown that a *low* dose is required to stop *reproduction* of *Trichinella spiralis* (the parasite responsible for causing trichinosis), but a much *higher* dose is needed in order to *eliminate* it from the pork.

Whole food items must be labeled if they are irradiated. A universal symbol of irradiation, namely, the radura symbol, is used for recognition of irradiated food. In the United States, the words "Treated with Radiation" or "Treated by Irradiation" also may appear with the symbol. Spices do not require this labeling. Processed foods that contain irradiated ingredients or restaurant foods prepared using irradiated ingredients do not require an irradiation label.

Research has been conducted on the sensory aspects of irradiated food. It is reported that, "The sensory appeal of foods which are processed with irradiation at levels that are approved for use is quite good. Researchers who have conducted experimental studies using sensory panelists to evaluate such foods found that food freshness, color, flavor, texture, and acceptability are not significantly different from unirradiated foods" (13). Due to its cold process of food preservation, the nutritive value of irradiated food is not significantly different from food subject to alternate methods of preservation, including canning.

Irradiation preserves food by killing insects and pests. It also kills microorganisms. With regard to food safety, food is made safer by the elimination of disease-causing bacteria such as *E. coli and Salmonella* and the parasite *Trichinella spiralis*. Irradiated food lasts longer and there are reduced losses due to spoilage (14).

Low doses of irradiation may be used to slow fruit ripening and control pests, without the use of pesticides. The process of irradiation leaves no residue.

Food irradiation facilities exist for the irradiation of foods, whereby the food product is sent off site for treatment. As well, in-line irradiation brings the technology to a company's own production line. A large defense contractor that radiates medical supplies now is using electron beams to pasteurize/irradiate meat, including prepared meats and other foods (15). A patent was awarded to this corporation for development of a miniature version of their chamber that could incorporate the electronic pasteurization into food producer's processing line. Both cost and convenience issues need to be addressed by a company considering irradiation of its products.

While irradiation of meat and poultry has received the approval of every major government and health agency in the United States, consumer health activists have yet to give their stamp of approval. As a result, meat companies are proceeding at a less than full-steam-ahead rate with irradiation (16).

The General Accounting Office (GAO) reports to the US House Committee on Commerce has stated that the benefits of irradiation outweigh any risks. "Food safety experts believe that irradiation can be an effective tool in helping to control foodborne pathogens and should be incorporated as part of a comprehensive program to enhance food safety"

Ohmic Heating

Ohmic heat processing of foods is relatively new for food manufacturers. In place of radiant heat, an electrical current is passed through food to heat it rapidly. A continuous heating system reaches the food as it passes between electrodes. An advantage of ohmic heating is that this system of heating prevents surface drying and overcooking while heating to control pathogenic microorganisms (17).

In ohmic heating, the *liquid* portion of the food, such as stew or soup, is heated rapidly and it conducts heat rapidly to the *inner* portion. In comparison, conventional heating tends to overprocess the surrounding liquid as it conducts heat to the inner portion; thus, quality is diminished.

DIRECT CONTACT PRODUCTS

Other antimicrobial, direct contact products, including lactoferrin (naturally occurring protein in mammalian milk), cetylpyridinium chloride [trade name "Cecure," for ready-to-eat (RTE), ready-to-cook and processed foods, not only meat] and acidified sodium chloride [(ASC), for comminuted, formed RTE products, and produce] are promising (16).

NUTRITIVE VALUE OF PRESERVED FOODS

There is no question regarding the importance of preserving factors such as the appearance, texture, and flavor of food. Yet, in a discussion of food preservation and the extension of a food's shelf life, preservation of nutritive value also becomes important. For example, prolonged or improper storage may have a deleterious effect on food due to the Maillard reaction. Perhaps water-soluble vitamins may be lost from a food or high levels of sugar or salt may be added. These and more become issues to address with regard to nutritive value of preserved foods.

Irradiated fresh produce, such as bagged salad, now may be a healthful addition to the diet of the young, elderly, pregnant, and immunocompromised individuals. The microbial load can be drastically cut, assuring less likelihood of *Shigella* and *E. coli* (18).

SAFETY OF PRESERVED FOODS

The safety of preserved foods must be taken into account when seeking to store and extend the shelf life of foods. The processor/manufacturer's good manufacturing practices (GMP's), the FDA's inspection, and the consumer's attentiveness all contribute to ensuring that food is properly preserved, stored, and not held beyond acceptable time parameters.

CONCLUSION

Food is preserved by methods such as *heat*, either mild—such as blanching or pasteurization—or severe including canning; *cold*, either refrigeration or freezing; *dehydration*; use of *added preservatives*, or *radiation*, including microwave heat, irradiation, or *ohmic heating*. Storage conditions and preservation processes are subject to FDA inspection and enforcement. Consumer vigilance also is necessary in order to preserve food. Environmental control of oxygen and water availability and enzymatic control extend shelf life of food and assist in providing food safety.

GLOSSARY

Blanching: Mild heat treatment that inactivates enzymes that would cause deterioration of food during frozen storage.

Canning: An example of a food processing method that involves *severe* heat treatment. Food is placed inside a can, the lid is sealed in place, and the can then is heated in a large commercial pressure cooker known as a retort.

Commercial sterility: Severe heat treatment. A sterilization where all pathogenic and toxin-forming organisms have been destroyed as well as all other types of organisms which, if present, could grow in the product and produce spoilage under normal handling and storage conditions.

Concentration: Method of removing some of the water from a food to decrease its bulk and weight. Concentration does not prevent bacterial growth.

Conduction: Transfer of heat from one molecule to another molecule; the major method of heat transfer is through a solid.

Convection: Flow or currents in a heated liquid or gas.

***D* Value**: Decimal reduction time; time in minutes at a specific temperature required to destroy 90% of the organisms in a given population.

Dehydration: A means of preservation with the primary intent to decrease moisture content and preclude the possibility of microbial growth such as bacteria, mold, and yeast.

Irradiation: The administration of measured doses of energy that are product-specific. It reduces the microbial load of a food, kills insects, controls ripening, and inhibits the sprouting of some vegetables.

Ohmic heat: In place of radiant heat, a continuous electrical current is passed through food to heat it rapidly, maintaining quality.

Pasteurization: Mild heat treatment that destroys pathogenic bacteria and most non-pathogens. It inactivates enzymes and extends shelf life.

Radiation: Fastest method of heat transfer; the direct transfer of heat from a radiant source to the food being heated.

Thermal death rate curve: Provides data on the rate of destruction of a specific organism in a specific medium or food at a specific temperature.

Thermal death time curve: Provides data on the destruction of a specific organism at different temperatures.

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CHAPTER 18

Food Additives

INTRODUCTION

According to the Food and Drug Administration (FDA), a food additive in its broadest sense is any substance added to food. *Legally*, the term refers to "any substance the intended use of which results or may reasonably be expected to result directly or indirectly in its becoming a component or otherwise affecting the characteristics of any food." (FDA)

Additives are useful in controlling such factors as decomposition and deterioration, nutritional losses, loss of functional properties and aesthetic value, but may not be used to disguise poor quality. Their use is subject to regulation in the 1958 Food Additives Amendment to the Food, Drug and Cosmetic (FD&C) Act with exemptions for prior sanctioned items and generally recognized as safe (GRAS) substances.

Food processors must petition the federal Food and Drug Administration (FDA) for approval of a new food additive. FDA approval then is required for use at *specific* levels only in specific products.

Vitamins and minerals are a special category of food ingredients. They are essential for nutrition but their use *apart from food* often is surrounded with controversy. Their use *in foods* has been *increasing* as they have been associated with the prevention and/or treatment of at least four of the leading causes of death in the United States. Existing additives, as well as new ones, are utilized in new product development.

Controlling decomposition, nutritional losses, and losses of functional properties, aesthetic value, and so forth are of utmost importance to our food supply. "Yuck, this stuff is full of ingredients!" says Linus, reading a can label in Charlie Brown. "Whether an additive is natural or artificial has no bearing on its safety."

DEFINITION OF FOOD ADDITIVES

The 1958 Food Additives Amendment to the Food Drug and Cosmetic Act of 1938 legally defined a food additive and the Committee on Food Protection of the National Research Council (NRC) more simply and practically defined an additive as: “A substance or a mixture of substances, other than a basic foodstuff, that is present in a food as a result of an aspect of production, processing, storage, or packaging.”

Exemption from food additive regulation are *prior sanctioned* substances, determined as safe for use prior to the 1958 amendment, such as sodium nitrite and potassium nitrite, and GRAS substances such as salt, sugar, spices, vitamins, and monosodium glutamate (discussed later).

A food ***additive*** in its *broadest sense* is any substance added to food. *Legally*, additives are classified as *direct* or *indirect*. If they are intentionally or purposely added to foods, these direct additives must be named on food labels. If *indirect*, they are incidentally added to food in very small amounts during some phase of production, processing, storage, packaging, or transportation.

According to the FDA, food additives are substances added to foods for specific physical or technical effects. They may not be used to disguise poor quality but may aid in preservation and processing or improve the quality factors of appearance, flavor, nutritional value, and texture (Chapter 1).

The consumer may be skeptical of or perhaps in opposition to an uncommon or unfamiliar chemical name of a food additive. Yet, in fact, all additives, including GRAS substances, such as salt, are chemicals. Food additives undergo rigorous toxicological analysis before their approval and use in foods.

The Joint FAO/WHO (Food and Agriculture Organization of the United Nations, and the World Health Organization) Expert Committee on Food Additives (JECFA) represents an international expert scientific committee that has met since 1956 to evaluate the safety of food additives.

FUNCTION OF FOOD ADDITIVES

General categories of food additives include *preservatives*, *nutritional additives, sensory agents*, and *processing agents* as noted below. When new food products are developed, new or existing food additives may be utilized. See http://www.washingtonwatchdog.org/documents/cfr/title21/part172.html

“Additives perform a variety of useful functions in foods that are often taken for granted. Since most people no longer live on farms, additives help keep food wholesome and appealing while en route to markets sometimes thousands of miles away from where it is grown or manufactured. Additives also improve the nutritional value of certain foods and can make them more appealing by improving their taste, texture, consistency or color.

Some additives could be eliminated if we were willing to grow our own food, harvest and grind it, spend many hours cooking and canning, or accept increased risks of food spoilage. But most people today have come to rely on the many technological, aesthetic and convenience benefits that additives provide in food.”

Food manufacturers attempt to increase the shelf life of their products by controlling and preventing deterioration; therefore, additives may be used to *preserve* or combat *microbial* or *enzymatic deterioration*. All living tissue resists microorganism attack to some degree, and additives assist in microbial (pathogens and nonpathogens) protection. The use of additives at the point of manufacture or processing *cannot stop all* foodborne illness though and *cannot guarantee* food safety for the population at large. For example, mishandling of food at restaurants and homes contributes a larger portion of foodborne illness than handling at food processing plants.

A second use of food additives is that they may be included in food *to maintain* or *improve nutritional value*. They *enrich*, *fortify*, or restore what is lost in processing. Additives may add nutrients and correct deficiencies, such as when *iodine* was used to treat goiter or when the minerals calcium and iron are added to food. Antioxidants such as lemon juice, BHT, BHA, and vitamins A and C are added to control the damaging effect of exposure to oxygen, or vitamin D is added to fortify milk. Many grain products are enriched or fortified with thiamin to prevent the disease beriberi, niacin to control the devastating pellagra, and more recently, with folate to prevent the reoccurrence of neural tube defect. Nutritional fortification is of tremendous benefit to many people.

One of the above additives, in fact the very first food additive in the United States, was iodine. Its function was nutritional: to treat and prevent goiter, common in the Great Lakes and Pacific Northwest regions of the United States. With study it was found that those geographic regions were without *sea*water. Thus the soil, water, and crops in these regions were deficient in iodine, and the problem of goiter in local populations was prevalent. It was added to salt (because it was commonly consumed, and thus a good vehicle) in 1924 and iodized salt quickly became a common dietary source of iodine.

It is shown then that additives play a role in food protection and nutrition fortification. Other roles of additives are as flavor and color *sensory agents*. These agents may be added to food so that it is made *more appealing*. As well, additives may be included in *processing*, for example, to maintain product consistency, to emulsify, stabilize, or thicken a food.

LEGISLATION AND TESTING FOR ADDITIVES

The *FDA* regulates the inclusion of additives to food products subject to interstate commerce or import, by authority of the Food Additives Amendment (1958) and the Color Additives Amendment (1960) to the Federal Food, Drug and Cosmetic Act of 1938. The *USDA* regulates additives of meat and poultry products.

Approval of Additives

In order to gain approval for use of an additive, manufacturers must petition the FDA and:

- provide evidence of harmlessness of an additive at the intended level of use

- provide data from at least 2 years of feeding of at least two animals, male and female (usually dogs and rats)
- prove the safety, usually by utilizing an outside toxicology laboratory for testing

Manufacturers must show *evidence* that the additive is safe and that it will accomplish its intended effect (show usefulness and harmlessnes). Although *absolute safety* of any substance can never be proven, there must be a *reasonable certainty* of no harm from the additive under its proposed use. In the approval evaluation, a “typical” intake level is considered and additives are evaluated on a case-by-case basis.

Useful information includes animal tests and disappearance data. *Animal tests* are conducted to show effects of large doses and lifetime or generational feedings. *Market basket patterns of consumption studies* show disappearance data of food that is both produced and imported. The latter shows, on average, the 7-day intake of an adult male.

If the additive wins approval by the FDA, it is only for use at *specific levels* in *specific products*. For example, certain fat replacements may be approved only for addition to *savory snacks*. Then, subsequent to approval, periodic review of additives based on up-to-date scientific evidence occurs.

The FDA’s Adverse Reaction Monitoring System (ARMS) monitors and investigates complaints that are associated with and related to food and color additives, specific foods, or vitamin and mineral supplements. The FDA also has an Advisory Committee on Hypersensitivity to Food Constituents. Consumers should read product labels in order to determine specific ingredient information.

Delaney Clause

The ***Delaney Clause*** (named for the congressional sponsor Rep. James Delaney—NY) to the Food Additives Amendment states that *no* additive shown to cause cancer in humans or laboratory animals, regardless of the dose, may be used in foods. Proposed additives are not acceptable for use in the food supply if they have been documented to be *carcinogenic* by *any* appropriate test. Such legislation continues to be reviewed, as both finer detection methods to detect minute amounts of a carcinogen, previously *undetected*, and improvements in additive testing over the years have become available.

This detection and improvement in testing has led to the question of what *is* an appropriate test. For example, is there *any* substance that is *totally* safe at *any* level of ingestion? Or will testing document the presence of carcinogens? The real issue may be in regard to “*risk versus benefit*” of an additive, for an additive may pose a “risk,” but a risk is *not* a threat to life. On the other hand, a “benefit” of using the additive is that there is an improvement in the condition of a food.

Currently, the FDA must abide by the *mandate* of the Delaney Clause in approving food additives, but this may change in the future. Overall, the goal of *any* ingredient testing is to provide a safe food supply for the public.

Nutrition Labeling Education Act (NLEA)

Further legislation included the Nutrition Labeling and Education Act of 1990 (Chapter 20). It required that all food labels *must list additives*, such as certifiable color additives by the common or usual name. Labels contain valuable information that allows people who may have food or food additive sensitivities to select appropriate food.

MAJOR ADDITIVES USED IN PROCESSING

http://www.cfsan.fda.gov/~dms/eafus.html is an informatve food additive database. “This is an informational database maintained by the US Food and Drug Administration (FDA) Center for Food Safety and Applied Nutrition (CFSAN) under an ongoing program known as the Priority-based Assessment of Food Additives (PAFA). It contains administrative, chemical and toxicological information on over 2000 substances directly added to food, including substances regulated by the US Food and Drug Administration (FDA) as direct, ‘secondary’ direct, and color additives, and Generally Recognized As Safe (GRAS) and prior-sanctioned substances. In addition, the database contains only administrative and chemical information on less than 1000 such substances. The more than 3000 total substances together comprise an inventory often referred to as *‘Everything’ Added to Food in the United States* (EAFUS).”

FDA definitions of the labels that are found in the inventory are:

Label	Definition	
DOCTYPE	An indicator of the status of the toxicology information available for the substance in PAFA (administrative and chemical information is available on all substances):	
	ASP	Fully up-to-date toxicology information has been sought.
	EAF	There is reported use of the substance, but it has not yet been assigned for toxicology literature search.
	NEW	There is reported use of the substance, and an initial toxicology literature search is in progress.
	NIL	Although listed as added to food, there is no current reported use of the substance, and, therefore, although toxicology information may be available in PAFA, it is not being updated.

	NUL	There is no reported use of the substance and there is no toxicology information available in PAFA.
	BAN	The substance was formerly approved as a food additive but is now banned; there may be some toxicology data available.
DOCNUM	PAFA database number of the *Food Additive Safety Profile* volume containing the printed source information concerning the substance.	
MAINTERM	The name of the substance as recognized by CFSAN	
CAS RN OR OTHER CODE	Chemical Abstract Service (CAS) Registry Number for the substance or a numerical code assigned by CFSAN to those substances that do not have a CAS Registry Number (888nnnnnn or 977nnnnnn-series)	
REGNUM	Regulation numbers in Title 21 of the U.S. Code of Federal Regulations where the chemical appears.	

"To access the specific regulations listed below, type in the title number, **21**, and then the section and part numbers, *eg*, **184** and **1330** at the Government Printing Office web site."

Additives may be *naturally occurring* or *synthetic*. The additives most commonly used in the United States are GRAS flavor agents, along with baking soda, citric acid, mustard, pepper, and vegetable colors, which total greater than 98% by weight of all additives in the United States.

Foods may contain ingredients that are added prior to retail sale. Vegetables and fruits, for example, may be treated with pesticides before harvesting, and dyes, fungicides, and waxes may be applied to retard ripening or promote sales. *Sodium nitrites* may be deliberately added to prevent *Clostridium botulinum* growth and preserve color and *sodium phosphates* may be added for purposes of retaining texture and preventing rancidity.

An additive may serve multiple purposes and therefore be listed in several classes of additives. Some of the major additives used in processing are identified in the following text.

Anticaking Agents and Free-Flow Agents

Anticaking agents and free-flow agents inhibit or prevent lumping and caking in crystalline or fine powders, including salt and baking powder. Various silicates such as *aluminum calcium silicate, calcium silicate*, and *silicon dioxide*, as well as *tricalcium phosphate*, are examples of anticaking agents that may be added to powdered food.

Antimicrobials

Antimicrobials inhibit the growth of pathogenic or spoilage organisms. Most recognizable is *sodium chloride*, common table salt. Organic acids such as *acetic acid, benzoic acid, propionic*, and *sorbic acid* are utilized with low pH level food items. *Nitrites* and *nitrates* are used as antimicrobials in meat products to combat *C. botulinum*, while *sulfites* and *sulfur dioxide* are added to fruit juices and wine.

Antioxidants (Chapter 7)

The presence of oxygen may result in rancidity, including the formation of toxic products, deterioration of color, flavor, and nutritional values. Thus, antioxidants are added to combine with available oxygen to halt oxidation reactions. For example, antioxidants prevent or limit rancidity in fats and foods containing *fats*, stabilizing foods by preventing or inhibiting *oxidation of unsaturated fats and oils*, colors, and flavorings. Also, antioxidants prevent browning of cut *fruit*, by enzyme-catalyzed oxidation in *enzymatic oxidative browning* (Chapter 7).

Many antioxidants occur *naturally*, such as *ascorbic acid* (vitamin C), the *tocopherols* (vitamin E), *citric acid*, and some *phenolic compounds*. The most widely used *synthetic* antioxidants are *BHA* (butylated hydroxyanisole), *BHT* (butylated hydroxytoluene), *TBHQ* (tertiary butyl hydroxyquinone), and *propyl gallate*. These four synthetic antioxidants may be used alone or in combination with one another or another additive to control oxidation. They may be used to prevent oxidation in fat-containing *food* (up to 0.02% of the fat level) or in *food packaging*, such as in whole grain cereal boxes.

Many meat processors add *sodium ascorbate* or *sodium erythorbate (ethorbic acid)* to cured meat to maintain processed meat color and to inhibit the production of nitrosamines from nitrites. (Nitrites are antioxidants that also are used as curing agents.) Ethylenediaminetetracetic acid (*EDTA*) may be used as an antioxidant or for other purposes in food (see Sequestering Agents).

Bleaching and Maturing Agents (Chapter 6)

As freshly milled flour ages, it naturally whitens and improves in baking quality. Bleaching and/or maturing agents are *added* to flour either during or after the milling process to whiten and/or speed up the aging process. *Benzoyl peroxide* is added to bleach the yellowish carotenoid pigment to white and *chlorine dioxide* is added to mature flour for better baking performance. *Bromates* also may be common as is *hydrogen peroxide*, which is used to whiten milk for certain types of cheese manufacture.

Bulking Agents

Bulking agents such as *sorbitol, glycerol*, or *hydrogenated starch hydrolysates* are used in small amounts to provide body, smoothness, and creaminess that supplement the viscosity and thickening properties of hydrocolloids (colloidal material that binds water). They provide an oily or fatty mouthfeel and frequently are used in foods where sugar is reduced or absent. *Polydextrose* (Chapter 12) is an example of a bulking agent used when calories are limited in foods. It contains 1 cal g and is made from a mixture of glucose, sorbitol, and citric acid (89:10:1).

Coloring Agents

A color additive is any dye, pigment, or substance that imparts color when added or applied to a food, drug, cosmetic, or to the human body. The term "FD&C" is applied to *food color additives* approved by the FDA for food, drug, and cosmetic usage, "D&C" is used for approved *drug and cosmetic coloring agents*, and "External D&C" is granted to approved *color additives applied externally*. The *synthetic* coloring agents are assigned FD&C classifications by initials, the shade, and a number; for example, FD&C Red #40, and FD&C Yellow #5 (see: http://www.cfsan.fda.gov/~lrd/cfr70-3.html) It may be synthesized, isolated or extracted.

Coloring agents are added to foods because of the sensory appeal they provide, for the purpose of making processed foods look more appetizing. Colors may be lost in processing and therefore may be added. For example, colors are used in baked products, candies, dairy products such as butter, margarine, and ice cream, gelatin desserts, jams, and jellies in order to improve their appearance. It has been said that people "eat with their eyes" as well as their palates!

There are thousands of foods that use colors to make them look appetizing and attractive. The primary reasons for adding coloring agents include the following:

- Offsetting color loss due to exposure to air, light, moisture, and storage
- To correct natural variations in color or enhance color
- To provide visual appeal to wholesome and nutritious foods
- To provide color to foods that would otherwise be colorless, including "fun foods" and special foods for various holidays

Pigments may be derived from *natural* sources such as plant, mineral, or animal sources (Table 18.1), and if so, are *exempt* from FDA *certification* (see below), although they are still subject to *safety* testing prior to their approval for use in food. Some of the same ingredients added to foods for their health benefits also offer "natural" (uncertified) coloring. These include anthocyanins, carotenoids, chlorophylls, foods such as beets (betalains), cabbage, tomatoes (lycopene), and a number of other flowers, fruits, and vegetables.

Synthetic coloring agents are generally less expensive than natural colorants, are more intense, and have better coloring power, uniformity, and stability when exposed to environmental conditions such as heat and light. They may be water-soluble or made water *in*soluble by the addition of aluminum hydroxide. Only small quantities of granules, a paste, powder, or solution are needed in foods to achieve the desired coloring effect. Each batch of synthetic food color must be

TABLE 18.1 Colors Exempt from Certification (Uncertified)/Natural

- Annato extract (yellow-reddish orange)
- B-Apo-8′-carotenal[a] (orange)
- Beta-carotene
- Beet powder
- Canthaxanthin
- Caramel color (brown)
- Carrot oil
- Cochineal extract (red)
- Cottonseed flour, toasted, partially defatted, cooked
- Ferrous gluconate[a]
- Fruit juice
- Grape color extract[a]
- Grape skin extract[a]
- Paprika
- Paprika oleoresin
- Riboflavin
- Saffron
- Titanium dioxide[a]
- Turmeric (yellow)
- Turmeric oleoresin
- Vegetable juice

[a] Restricted to specific uses.

tested by both the manufacturer and the FDA prior to gaining approval. Such testing assures safety, quality, consistency, and strength of the color additive.

The FDA permitted nine "*certifiable*" colors in the 1906 Food and Drug Law under a *voluntary* certification program; seven of those were approved for addition to *food* (Table 18.2). Certification became *mandatory* in 1938, with authority for testing passing to the USDA. Today, the term "certifiable" food color refers to color additives that are synthetic, or *manmade*, not natural.

TABLE 18.2 Certifiable Colors—Synthetic

- FD&C Blue No. 1 (bright blue)
- FD&C Blue No. 2 (royal blue)—Indigotine
- FD&C Green No. 3 (sea green)—minimally used
- FD&C Red No. 3 (orange-red)—erythrosine
- FD&C Red No. 40 (cherry-red)—most widely used food dye
- FD&C Yellow No. 5 (lemon yellow)—tartrazine; second most widely used food dye
- FD&C Yellow No. 6 (orange)
  - Orange B[a] Citrus Red No. 2[a]—used on some orange skins

[a] Restricted to specified uses other than foods.

In 1982, the National Institutes of Health concluded that there was no scientific evidence to support the claim that coloring agents or other food additives caused hyperactivity.

Curing Agents (Chapter 9)

Curing agents impart color and flavor to foods. *Sodium nitrate* and *nitrite* contribute to the color, color stability, and flavor of cured meats such as bacon, frankfurters, ham, and salami. They also have antimicrobial properties to control *Clostridium botulinum* bacteria; in fact, since nitrite use in cured meats became common, there have been no reported cases of botulism linked with cured meats. Nitrites also inhibit the growth of *C. perfringens, Staphylococcus aureus*, as well as other nonpathogens during storage of cured meats. (A nitrite concern is that nitrites react with certain amines to produce carcinogenic nitrosamines. Repeated testing of cured meat products showed that nitrosamines were absent or present at very low levels. In fact, endogenous human saliva usually contains more nitrite than has been detected in cured meat. Therefore, with these test results, the FDA permits use of nitrates and nitrites at low levels, but has encouraged research on alternative ways of preserving meats.)

Dough Conditioners/Dough Improvers (Chapter 6)

Dough conditioners modify the starch and protein (thus, gluten) components of flour. They promote the aging process and improve both dough handling (such as in breadmaking machinery) and baking qualities (more uniform grain and increased volume). *Ammonium chloride, potassium bromate (bromination), diammonium phosphate*, and *calcium* or *sodium stearoyl lactylate* are processing aids that are examples of dough conditioners.

Some enzymes that provide food for yeast and emulsifiers may be included in this class of additives. Conditioners may include iodates, a dietary source of iodine.

Edible Films (Chapter 19)

Edible films become part of food, and therefore are subject to FDA approval. Examples include some *casings*, such as in sausage, and *edible waxes*, such as those applied to fruits and vegetables. The waxes function to improve or maintain appearance, prevent mold, and contain moisture while allowing respiration. Food may be coated with a thin layer of polysaccharides such as *cellulose, pectin, starch*, and *vegetable gums*, or proteins, such as *casein* and *gelatin* in order to extend shelf life.

Emulsifiers (Chapter 13)

Emulsifiers are a class of surface-active agents that improve and maintain texture and consistency in a variety of foods containing fat/oil and water. They contain both a hydrophobic molecular end, which usually is a long-chain fatty acid, and a hydrophilic end, and so act as a bridge between two immiscible liquids, forming an emulsion. For example, emulsifiers maintain a uniform dispersion by keeping water and oil fractions of a mixture together and they prevent large crystalline formations in products such as ice cream. *Lecithin*, *monoglycerides*, *diglycerides*, and *polysorbates* (Polysorbate 60, 65, and 80) are examples of emulsifiers.

Enzymes

Enzymes are nontoxic protein substances that occur *naturally* in foods or may be produced by *microorganisms* or *biotechnology* to catalyze various reactions. They are easily inactivated by a specific pH and temperature. Although the presence of some enzymes may produce negative quality changes, other enzymes often are intentionally added to foods for their beneficial effect. Microorganisms are responsible for producing some of the enzymes desired in foods; thus, the microbes may be intentionally added to food.

Some examples of enzymes that are additions to other foods include *bromelain* (from pineapples), *ficin* (from figs), and *papain* (from papayas). These enzymes act as meat tenderizers of muscle tissue or connective tissue. *Amylases* hydrolyze starch in flour and are used along with acids in the production of corn syrup. *Invertase* is used to hydrolyze sucrose and prevent its crystallization. *Pectinases* clarify pectin-containing jellies or juices; *proteases* may be used as meat tenderizers, to create cheeses from milk (rennin) and to produce soy sauce. *Glucose oxidase* is added to foods such as egg whites in order to prevent the Maillard browning.

Fat Replacers (Chapter 12)

Fat replacers include carbohydrate, fat, or protein-based replacers. They include the following:

- Hydrocolloids, the long-chain polymers that thicken or gel
- Hemicelluloses, a plant polysaccharide
- β-Glucans, a subgroup of hemicelluloses (used in milk)
- Soluble bulking agents
- Microparticulated cellulose, egg, milk, or whey proteins (such as Simplesse®)
- Composite materials such as gums with milk or whey solids or cellulose in combination with carboxymethyl cellulose
- Various functional blends of corn syrup solids, emulsifiers, modified food starch, nonfat milk solids, and vegetable protein
- Sucrose polyester (Olean®)

These ingredients are fat replacers that can be used alone or in combination to provide a fatty or oily mouthfeel (1).

Firming Agents

Firming agents, such as *calcium chloride*, act on plant pectins to control the softening that may accompany the canning process of fruits or vegetables.

Flavoring Agents

Flavoring agents are the *largest single group* of food additives. Food and beverage applications of flavors include dairy, fruit, nut, seafood, spice blends, vegetables, and wine flavoring agents. They may complement, magnify, or modify the taste and aroma of foods. There are over 1200 different flavoring agents used in foods to create flavor or replenish flavors lost or diminished in processing, and hundreds of chemicals may be used to simulate natural flavors. *Alcohols*, *esters*, *aldehydes*, *ketones*, *protein hydrolysates*, and *MSG* are examples of flavoring agents.

Natural flavoring substances are extracted from plants, herbs and spice, animals, or microbial fermentations. They also include essential oils and oleoresins (created by solvent extract with solvent removed), herbs, spices, and sweeteners.

Synthetic flavoring agents are chemically similar to natural flavorings and offer increased consistency in use and availability. They may be less expensive and more readily available than the natural counterpart, although they may not adequately simulate the natural flavor. Some examples of synthetic flavoring agents include *amyl acetate*, used as banana flavoring, *benzaldehyde*, used to create cherry or almond flavor, *ethyl butyrate* for pineapple, *methyl anthranilate* for grape, *methyl salicylate* for wintergreen flavor, and *fumaric acid*, which is an ideal source of tartness and acidity in dry foods.

Flavor enhancers such as *monosodium glutamate* (MSG) intensify or "bring out," enhance, or supplement the flavor of other compounds in food; they have a taste outside of the basic sweet, sour, salty, or bitter. Monosodium glutamate was chemically derived from seaweed in the early 1900s, but is manufactured commercially by the fermentation of starch, molasses, or sugar.

MSG is a GRAS substance to which a small percentage of the public is severely allergic. Therefore, MSG must be identified on food labels when it is included in food. However, it may be a portion of another compound, such as "hydrolyzed vegetable protein" (which may contain up to 20% MSG); in that case, MSG is not stated on the label. In a summary of several decades of research and one century of use, arguments *against* the GRAS status of MSG are overwhelmed by evidence *in support of* MSG.

Other examples of flavoring agents include the common salt (sodium chloride) and sugar (sucrose), corn syrup, aspartame (also a nutritive sweetener), autolyzed yeast (also a flavor enhancer), essential plant oils (such as citrus), ethyl vanillin and vanillin (a synthetic flavor compound), extracts (such as vanilla), glycine, mannitol (nutritive sweetener), saccharin (nonnutritive sweetener), and sorbitol (nutritive sweetener).

Fumigants

Fumigants are used to control pests and molds.

Humectants (Chapter 14)

Humectants are added to foods such as candy or shredded coconut in order to retain moisture content. The four polyhydric alcohols that are used to improve texture and retain moisture due to their affinity for water are *glycerol, mannitol*, and *sorbitol*, which also take moderately sweet, and *propylene glycol*. These may be functional in diet beverages, candy, stick chewing gum, and other foods to provide texture and sweetness. In order to prevent moisture absorption, *mannitol* may be "dusted" on chewing gum. *Glycerol monostearate* is another commonly used humectant.

Irradiation (Chapter 17)

Irradiation is subject to FDA approval as an *additive*. Only specific foods, dosages, and irradiation sources are approved to kill microorganisms such as *E. coli, Salmonella, Trichinella*, and insects.

Leavening Agents (Chapter 15)

Leavening agents leaven batters and doughs by producing or stimulating CO_2. Inorganic salts such as ammonium or phosphate salts such as *sodium acid pyrophosphate* may be combined with yeast, a biological leaven. *Sodium bicarbonate* (baking soda) or *ammonium bicarbonate* react with an acid to chemically produce CO_2.

Lubricants

Lubricants such as mineral hydrocarbons (nonstick cooking spray) may be added to food-contact surfaces to prevent foods from sticking and may become a part of the food.

Nutrient Supplements

Nutrient supplements are added to provide essential nutrients that are lost in processing or lacking in the diet. The addition of nutrients maintains or improves the nutritional quality of food. Common foods such as milk, cereal, flour, margarine, and salt contain added vitamins and minerals. For example, iodine may be added to salt and B vitamins (including thiamin, riboflavin, niacin, folate) and iron are added to grain products. This improves the nutritional status of individuals who might not otherwise obtain essential nutrients. Oftentimes, the nutrients may be encapsulated for addition to food products, and thus more intact.

Some examples of nutrient supplementation include the following:

Alpha tocopherol (vitamin E) is an antioxidant and nutrient. It is commonly used in vegetable oil.

Ascorbic acid (vitamin C) is an antioxidant that reacts with unwanted oxygen, stabilizing colors, flavors, fats, and oils in foods. It maintains the red color of cured meats and prevents the formation of nitrosamines (from sodium nitrite). It is a nutrient that is added to beverages, breakfast cereals, and cured meats. *Sodium ascorbate* is a more soluble form of ascorbic acid that may be added to foods. *Sodium erythorbate* (*erythorbic acid*) achieves the same purpose without adding nutritional value.

Beta carotene is a nutrient and coloring agent that may be added to butter, margarine, or shortening.

B vitamins—thiamin, riboflavin, niacin, pyridoxine, biotin, and folate.

Calcium pantothenate and other forms of calcium are added to supply calcium.

Ferrous gluconate is a nutrient and coloring agent. It may be added to foods such as black olives to create a jet black color. *Ferric orthophosphate, ferric sodium pyrophosphate*, and *ferrous fumarate* may be added to supply iron. *Ferrous lactate* is also a GRAS color fixative for ripe olives.

Phosphates in the form of *phosphoric acid* acidifies and flavors food; *sodium aluminum phosphate* is a leavening agent; *calcium* and *iron phosphate* act as mineral supplements to food.

Vitamins A and D are added to improve the nutritive value of foods such as margarine and reduced-fat and nonfat milks.

Minerals such as *iodine* and *zinc* may be added to foods.

pH Control Substances

Natural or synthetic *acid* or *alkali* ingredients change or maintain the initial pH of a product. For example, acidulents flavor, preserve, and regulate pH. The acid ingredients regulate by lowering the pH and preserve foods by inhibiting microbial growth. Regardless of the acid level of food ingredients, food acids are incorporated into foods in order to maintain a constant acid level. *Natural acids* include the following: *acetic acid*, or vinegar, and *citric acid* from citrus, which controls unwanted trace metals otherwise catalyzing oxidation reactions; *malic acid* (an organic acid from apples and figs); and *tartaric acid* (a weak acid). These acids may be added to foods to impart flavor and control tartness. *Lactic acid*, present in almost all living organisms, is an acidity regulator and is used in balancing the acidity in cheesemaking, as well as adding tartness to many other foods. The acid salt *calcium propionate* is added to control pH of breads. *Sodium lactate* (the salt of lactic acid) may be used in processed meat and poultry products.

Examples of *alkaline* ingredients include *sodium bicarbonate* (baking soda), an ingredient that balances the acid component of baking powder, *sodium hydroxide*, used in modified starches, and *potassium hydroxide*. Alkaline compounds are used to neutralize excess acid that otherwise could produce unwelcome flavors. In food they leaven and soften hard water.

Preservatives

Preservatives are classified as either *antimicrobial* agents, which prevent microbial growth (bacteria, mold, yeast), or *antioxidants*, which halt undesirable oxidative changes in food. They are used to delay natural deterioration, thus extending the shelf life of foods.

A preservative may be used alone or in combination with other additives or preservation techniques such as cold temperature storage, heat preservation, or dehydration (Chapter 17). Preservation is offered by the use of *salt* or *sugar,* which competes with bacteria for water, and therefore lowers the water activity (A_w) of the food. *Calcium or sodium propionates* and *potassium sorbate* are additives used to control mold and bacterial growth, such as the bacilli that causes “rope” in breads. *Sodium benzoate* inhibits mold and yeast growth in condiments, fruit juices, and preserves.

Sulfur dioxide inhibits unwanted enzymatic oxidative browning in fruits and vegetables; it also prevents wild yeast growth in the wines used to produce vinegar and is legally used on grapes. However, a small number of individuals are severely allergic to sulfites, thus, they were banned in 1986 from addition to products not ubject to further cooking (eg, many salad bar items).

Nitrites, such as *sodium nitrite,* are effective preservatives, preventing the growth of *C. botulinum* and adding flavor and retaining meat color in cured meats. *Antibiotics* are incorporated into animal feed and function as preservatives, but may *not* be added to human food. Some weak acids or *acid salts* and *chelating agents* (which tie up unwanted traces of metal) are utilized as preservatives.

Propellants

Propellants and aerating agents provide *pressure* needed for aerosol can products to be expelled and to *add air* to a product. Carbon dioxide, nitrogen, nitrous oxide, and other gases may be used in aerosol containers, such as containers of “whipped topping.”

Sequestrants

Sequestrants are known as chelating agents or metal scavengers. They are substances that *bind* or combine with trace amounts of unwanted metals such as copper and iron, making them unavailable for participating in negative reactions such as deterioration in food. They form *inactive complexes* with metallic ions during processing and storage, and therefore prevent metals from catalyzing reactions of fat oxidation, pigment discoloration, and flavor or odor loss and from causing cloudy precipitates in beverages such as tea. They protect vitamins from oxidation. Examples of sequestrants include citric and *malic acid, ethylenediaminetetraacetic acid (EDTA)*, and *polyphosphates*.

Solvents

Solvents are used to separate substances by dissolving a substance in the solvent and removing the solvent.

Stabilizers and Thickeners

Stabilizers and thickeners function variously in food. For example, they provide consistency and texture to many foods. They are water-holding substances added to stabilize, gel, or thicken foods by absorbing some of the water present in foods. They increase viscosity of the final product, prevent ice crystal formation, or form gels. Stabilizers or thickeners are added for appearance and mouthfeel, to protect emulsions, and to contain volatile oils that would otherwise evaporate. Most are polysaccharides, and pectin, gums, and mucilages are a source of soluble fiber to the diet.

Soluble fiber in the daily diet is of benefit to health in several manners:

1. Reduces "bad" LDL cholesterol: as soluble fiber travels through the GI tract, it binds to bile acids which are made of cholesterol; it therefore limits the amount of cholesterol absorbed, hence, lowering blood cholesterol.
2. Aids digestive system: manages "regularity" and protects against colon and colorectal cancer, diverticular disease, irritable bowel syndrome, and gallstone development.
3. Manages diabetes mellitus: slows the absorption of glucose from the small intestine.

Soluble fibers include the following:

- *Alginates* (from kelp).
- *Carrageenan* (a seaweed derivative).
- To provide visual appeal to wholesome and nutritious foods.
- *Cellulose* may be reacted with derivatives of acetic acid to form sodium carboxymethylcellulose (CMC), which is used to prevent sugar crystallization.
- *Dextrins*.
- The hydrocolloids (colloidal material that holds water); *gelatin* (the protein from animal bones, hoofs, etc.), *gums* such as arabic, guar, and locust beans, and *pectin*. Some beneficial effects of including these is an inclusion of *soluble fiber* in the diet. Manufacturers use *pectin* as a stabilizer and thickener in candies, frozen desserts, jams, jellies and preserves. *Gums* and *mucilages* offer soluble fiber too. They are found in oatmeal, oat bran, and dried beans.
- Propylene glycol.

- *Protein derivatives* such as casein or sodium caseinate and hydrolyzed vegetable protein.
- *Starches* (including amylose and modified starches) allow oils, water, acids, and solids to remain well mixed by the addition of natural or chemically modified starches.

Some stabilizers and thickeners are commercially available for use by the health care industry in preparation of food items such as pureed foods.

Surface-Active Agents

Surface-active agents are organic compounds that are used in food systems to reduce the surface tension or forces at the surface of a liquid. Dispersion into food mixtures is resisted if the forces attracting surface molecules of a liquid to one another is not reduced. Classifications of surface-acting agents include wetting agents, lubricants, dispersing agents, and emulsifiers. For example, *wetting agents* reduce surface tension in chocolate milk mixes, so that particles to be mixed may absorb water more easily and mix into the milk. *Emulsifiers* enable two ordinarily immiscible substances to combine—for example, oil and water—and they also improve texture.

Sweeteners (Chapter 14)

Sweeteners are added to many foods and beverages. The disaccharide *sucrose* (table sugar) is a common food additive. *Fructose* is one of the components of sucrose. It is two times as sweet as sucrose and will not crystallize out of solution as does sucrose. It is the most water-soluble sugar and is used to create a very sweet solution. It is hygroscopic, and therefore may function as a humectant. *Lactose* (milk sugar) and *maltose* (malt sugar) often are food additives. *Corn syrup, high-fructose corn syrup, honey*, *maple syrup sugar*, and *molasses* are other examples of sweeteners used as food additives. *Invert sugar* is the 50:50 mixture of glucose and fructose produced by enzymatic or acid treatment of sucrose. Its use prevents sugar crystallization, for example, in the liquid center of chocolate-covered cherries.

Sweeteners, Alternative (Chapter 14)

Some low-calorie, artificial sweeteners, and sugar alcohols that are added to foods include the following:

- **Acesulfame K** may be used alone or in combination with other sweeteners. It is a synthetic derivative of acetoacetic acid that is not metabolized by the body and therefore is excreted unchanged. Acesulfame is stable in heat and is many times sweeter than sucrose with no bitter aftertaste.
- **Aspartame** is a synthetic dipeptide (aspartic acid, phenylalanine). It is in products used by diabetics but cannot be used by phenylketonuric (PKU)

individuals. It is not stable in heat unless encapsulated and cannot substitute for sucrose when the texture of the food depends on solids content.

- **Cyclamates** of sodium, calcium, magnesium, and potassium are approximately 30 times sweeter than sucrose (not used in the United States).
- **Saccharin** is used as the calcium or sodium salt. It cannot be used as a substitute for sucrose when the texture of the food depends on solids content.
- **Sugar alcohols** include *mannitol*, *sorbitol*, and *xylitol*.

NUTRIENT SUPPLEMENTS IN FOOD

As previously stated, the nutritive value of foods may be improved either by replacing nutrients lost in processing or lacking in the diet. The addition of *vitamins*, such as vitamin C, and *minerals*, such as calcium, often is made to common foods. Further detail appears in this section.

Food processors may choose to add any number of nutrient additives, at varying levels, to their food products. Products are enriched when nutrients that were *lost during processing* are replaced to levels comparable to the original levels. ***Enrichment*** is designed to prevent inadequacies in certain segments of the population, and it is the addition of nutrients to achieve established concentrations specified by the standards of identity (2). ***Fortification*** is the addition of nutrients (the same or different ones) at levels *higher* than those found in the original or comparable food. It can correct existing deficiencies in segments of the population, such as with the addition of calcium. Breakfast cereals, breakfast bars, and fruit drinks are prominent examples of fortification that provide needed nutrients to many individuals.

In addition to the enjoyment of eating, consumption of a varied diet offers many health benefits to the consumer, including nutrients such as vitamins and minerals as well as nonnutrient compounds (such as phytochemicals) that play an important role in reducing risks of certain diseases. For additional information, the reader is referred to the FDA's regulation of dietary supplements (3).

Endorsement of Nutrient Supplementation in Foods

The American Medical Association Council on Foods and Nutrition Board has set the following recommendations for endorsement of nutrient supplementation in foods:

1. The intake of the nutrient is below the desirable level in the diets of a significant number of people.
2. The food used to supply the nutient is likely to be consumed in quantities that will make a significant contribution to the diet of the population in need.
3. The addition of the nutrient is not likely to create an imbalance of essential nutrients.
4. The nutrient added is stable under proper conditions of storage.

5. The nutrient is physiologically available from the food.
6. There is a reasonable assurance against excessive intake to a level of toxicity.

Vitamins and Minerals Manufactured for Addition to Foods

There are many vitamins and minerals that are prepared for addition to foods. The *fat-soluble vitamins* that may be added to foods are the carotenoids, vitamin A precursors, the tocopherols (vitamin E), and vitamin D.

Among the *water-soluble vitamins*, ascorbic acid (vitamin C) may be added to foods in order to prevent oxidation, to prevent the formation of nitrosamines in cured meats, and to improve nutritive value, especially in beverages. The B-complex vitamins may be used as nutrient additives. *Thiamin hydrochloride* and *thiamin nitrate* (B_1), *riboflavin* and *riboflavin-5′-phosphate* (B_2), and several sources of *niacin* (B_3) are FDA approved and commercially available to processors for addition to foods.

Vitamin B_6 (pyridoxine, pyridoxal, and pyridoxamine), B_{12} (cyanocobalamin), pantothenic acid, folacin, and biotin also are manufactured for use in food. Recently, folic acid (folacin, folate) addition has been required by the FDA for addition to flour and flour-based products. Folate has been shown to prevent neural tube defect (4).

Additionally, among *minerals*, there are three major minerals and six trace minerals used in foods. Of the major minerals, calcium, magnesium, and phosphorus may be added to a number of foods. Calcium is now more commonly added to orange juice. Copper, fluoride, iodine, iron, manganese, and zinc are trace minerals used as food additives. Chromium, potassium, molybdenum, selenium, and sodium may not have reference daily intakes (RDIs), but rather safe and adequate intakes. Labels do not state these values but may state "reduced sodium" and so forth if the statement is in compliance with NLEA regulations.

Functional Foods (more in Appendices)

Eating modified foods may supply health benefits beyond the traditional nutrients a food contains. Therefore, food products may be modified by the addition of nutrients not inherent to the original counterpart (5). A newly evolving area of food and food technology is ***functional foods*** (Chapter 20), which are defined as

"Any modified food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains" (6, 7).

Phytochemicals (more in Appendices)

Phytochemicals (Chapters 7 and 20), nonnutrient substances from plants (plant chemicals), may become useful as food additives because they may play an important role in reducing risk of cancers. They are naturally available in the diet and are currently in supplement form. Phytochemicals are defined as:

> "Substances found in edible fruits and vegetables that may be ingested by humans daily in gram quantities and that exhibit a potential for modulating human metabolism in a manner favorable for cancer prevention" (6).

Functional food components, along with phytochemicals, have been associated with the treatment and/or prevention of at least four of the leading causes of death in the United States—cancer, diabetes, cardiovascular disease, and hypertension. They have been associated with the treatment and/or prevention of other medical maladies including neural tube defect and osteoporosis, as well as abnormal bowel function and arthritis (8).

It is the position of the American Dietetic Association (ADA) that specific substances in foods (eg, phytochemicals and naturally occurring components and functional food components) may have a beneficial role in health as part of a varied diet. The association supports research regarding the health benefits and risks of these substances. Dietetics professionals will continue to work with the food industry and government to ensure that the public has accurate scientific information in this emerging field (ADA).

Nutraceuticals (more in Appendices)

The term "nutraceutical" (Chapter 20) is not recognized by the FDA and is outside FDA regulations because of the following:

- ***Foods*** are defined as "products primarily consumed for their taste, aroma, or nutritive value."
- ***Drugs*** are defined as "intended for use in the diagnosis, cure, mitigation, treatment or prevention of disease or to affect the structure or a function of the body" (10).
- ***Nutraceuticals*** are defined by the Foundation For Innovation in Medicine as "Any substance that may be considered a food or part of a food and provides medical or health benefits, including the prevention or treatment of disease. Nutraceuticals may range from isolated nutrients, dietary supplements, and diets to genetically engineered "designer" foods, herbal products, and processed products, such as cereals, soups, and beverages" (9).

Formulating a New Product with Vitamin or Mineral Addition

Food processors may choose to use any additive, including nutrients or nonnutrient supplements, in the manufacture of food products. Regardless of what is used, they must comply with all Nutrition Labeling and Education Act (NLEA) regulations regarding the contents and stated ***health claims*** of their products. They must use vitamin and mineral additives judiciously (not just to enhance the values on their food label), and then only make label claims regarding nutritional benefits that are allowed (Chapter 20).

Food technologists formulate a new product with a number of considerations in mind regarding vitamin and mineral addition (2). Some considerations include the following:

- Overall product composition—such as pH, water activity, fat, fiber, protein, because the flavor and color of foods may change.
- Ingredient interactions—of a vitamin or mineral combination.
- Processing considerations—blanching, washing, stability to heat.
- Shelf life and packaging—protection from oxidation or light.
- Cost factors—price of the nutrient, overages due to loss, and costs of (the above) processing and packaging needs.

A research dietitian with the USDA Agricultural Research Services has said: "Open, academic research, including human testing of isolated food components (eg, vitamins, minerals, amino acids, fatty acids, sugars, dietary fibers, and many other food components) has been fundamental to the development of nutrition science. Federal regulations (through FDA) and funding should be encouraged to promote human research and clinical testing of the health benefits of foods and food components, consistent with good science, safety, and the Nutrition Labeling and Education Act of 1990.

Although compounds in foods that must be concentrated to obtain physiologic effects should be regulated as drugs, foods and purified food constituents in amounts commonly consumed should not be classified as drugs simply because they are being tested for potential health effects or disease prevention. Research should not be discouraged by requiring investigative new drug procedures for substances in amounts available in the diet" (10).

CONCLUSION

Additives are "a substance or a mixture of substances, other than a basic foodstuff, that is present in a food as a result of an aspect of production, processing, storage or packaging." Additives function in foods to combat microbial and enzymatic deterioration, to maintain or improve nutritional value and product consistency and to make food more aesthetically appealing. *Less* rancidity, spoilage, contamination, and overall waste, and *more* nutritional value and ease of preparation are possible with the use of additives. Many additives are natural food ingredients, used strictly for imparting flavor and color.

The Food Additives Amendment (1958) of the Federal Food, Drug and Cosmetic Act of 1938 contains legislation regarding the safety of additives. The Delaney Clause to the Food Additives Amendment requires testing of proposed additives in the United States for carcinogens. Salt, sugar, and corn syrup are the three most commonly used food additives in the US food supply.

Major additives used in food processing include alternative sweeteners, anticaking agents, antioxidants, bleaching and maturing agents, bulking agents, coloring agents, curing agents, dough conditioners, emulsifiers, enzymes, fat replacers, firming agents, flavoring agents, fumigants, humectants, irradiation, leavening agents, lubricants, nutrient supplements, pH control substances, preservatives, propellants, sequestrants, solvents, stabilizers and thickeners, surface acting agents, and sweeteners.

The nutritional value of foods may be increased to exceed nutrient levels inherent in the traditional product. Food nutrients may be fortified or enriched. Specific vitamins and minerals are manufactured with the purpose of addition to foods. Functional foods are foods that are modified to provide a health benefit beyond the traditional product and may be used to treat/prevent disease. They along with phytochemicals and nutraceuticals are a newly evolving area of food and food technology.

"Consumers are demanding cleaner ingredient statements without unfamiliar and "chemical sounding" names while expecting increased shelf life and product quality". (http://www.gftc.ca/articles/2001/baker07.cfm)

GLOSSARY

Additive: Substance added to foods for specific physical or technical effects.
Delaney Clause: Clause added to Food Additives Amendment stating that no additive shown to cause cancer in humans or laboratory animals could be used in foods.
Drugs: Intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease or to affect the structure or function of the body.
Enrichment: The addition of nutrients to achieve established concentrations specified by the standards of identity.
Foods: Products primarily consumed for their taste, aroma, or nutritive value.
Fortification: The addition of nutrients at levels higher than those found in the original or comparable food.
Functional foods: Any modified food or food ingredient that may provide a health benefit beyond that obtained by the original food; the term has no legal or general acceptance in the United States, but is accepted by some as food for specified health use.
Generally Recognized as Safe (GRAS): Substances in use, not shown to be unsafe.
Health claims: Describe an association between a nutrient or food substance and disease or health-related condition.
Nutraceuticals: The name given to a proposed new regulatory category of food components that may be considered a food or part of a food and may supply medical or health benefits including the treatment or prevention of disease; a term not recognized by the FDA.
Phytochemicals: Plant chemicals; natural compounds other than nutrients in fresh plant material that function in disease prevention; they protect against oxidative cell damage or facilitate carcinogen excretion from the body and exhibit a potential for reducing the risk of cancer.

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CHAPTER 19

Packaging of Food Products

INTRODUCTION

Packaging is intended to preserve food against spoilage and contamination and extend the shelf life. It provides containment (holding the product), protection (quality, safety, freshness), information (graphics, labels), and utility of use or convenience (1). Yet, packaging offers much more than these benefits to the manufacturer and consumer. There exists various packaging materials, including films, and package oxygen levels that protect foods from air. Packaging also may maintain time-sensitive foods and use dating or doneness indicators. It may be used as a promotion tool on store sales shelves.

Packaging materials for food include metal, glass, paper, plastics, foil, wood crates, cotton, or burlap (jute). Food may be vacuum packaged, subject to controlled or modified atmospheric packaging, or be aseptically packaged. Manufacturers must adhere to FDA regulations regarding both the method and materials of packaging.

Today, consumer-convenient packaging such as microwaveable packages, single-serve products, tubs, and zippered pouches, tamper evidence, and package atmosphere have become increasingly important as a packaging selection (2). Packaging functionality is a demand of both consumers and food companies alike, who want packaging/materials that meet their needs. Of course there is an emphasis on "green".

TYPES OF PACKAGING CONTAINERS

Packaging containers are classified as primary, secondary, and tertiary. A ***primary*** container is the bottle, can, drink box, and so forth that contains food. It is a *direct*-food-contact surface, and therefore is subject to approval by the Food and Drug Administration (FDA), which tests for the possible migration of packaging materials into food.

Several primary containers are held together in ***secondary*** containers, such as corrugated fiberboard boxes (commonly, but not correctly, referred to as cardboard), and do *not* have *direct* food contact. In turn, several secondary containers are bundled into ***tertiary*** containers such as corrugated boxes or overwraps that prepare the food product for distribution or palletizing. This offers additional food protection during storage and distribution where errors, such as dropping and denting or crushing cartons, may occur. Tertiary containers prevent the brunt of the impact from falling on the individual food container.

PACKAGING FUNCTIONS

The functions of packaging are numerous and include such purposes as protecting *raw* or *processed* foods against *spoilage* and *contamination* by an array of external hazards. Packaging serves as a barrier in controlling potentially damaging levels of light, oxygen, and water. It facilitates ease of use, offers adequate storage, conveys information, and provides evidence of possible product tampering. It achieves these goals by assisting in the following manners:

- Preserving against spoilage of color, flavor, odor, texture, and other food qualities.
- Preventing contamination by biological, chemical, or physical hazards.
- Controlling absorption and losses of O_2 and water vapor.
- Facilitating ease of using product contents, such as packaging that incorporates the components of a meal together in meal “kits” (eg, tacos).
- Offering adequate storage before use, such as stockable, resealable, pourable.
- Preventing/indicating tampering with contents by tamper-evident labels.
- Communicating information regarding ingredients, nutrition facts, manufacturer name and address, weight, bar code information, and so forth via package labeling.
- Marketing, standards of packaging, including worldwide acceptability of certain colors and picture symbols vary and should be known by the processor. Packages themselves may promote sales. They may be rigid, flexible, metallized, and so forth, and also may carry such information as merchandising messages, health messages, recipes, and coupons.

PACKAGING MATERIALS

In choosing the appropriate packaging for their product, packers must consider many variables. For example, *canners* must make packaging choices based on cost, product compatibility, shelf life, flexibility of size, handling systems, production line filling and closing speeds, processing reaction, impermeability, dent and tamper resistance, and consumer convenience and preference (3).

Processors who use *films* for their product must select film material based on its “barrier” properties that prevent oxygen, water vapor, or light from negatively affecting the food. As an example, the use of packaging material that prevents light-induced reactions will control degradation of the chlorophyll pigment, bleaching or discoloration of vegetable and red meats, destruction of riboflavin in milk, and oxidation of vitamin C. Some films are heat stable for cooking applications, and some show cold temperature resistance in refrigerated or frozen storage.

The most common food packaging materials include metals, glass, paper, and plastic. Some examples of these leading materials appear in the following text.

Metal

Metals such as steel and aluminum are used in cans and trays. A metal can forms a hermetic seal, which is a complete seal against gases and vapor entry or escape and it offers protection to the contents. The trays may be reusable or disposable recyclable trays and either steam table or No. 10 can size. Metal also is used for bottle closures and wraps.

Steel has a noncorrosive coating of tin inside, thus the name “tin can,” whereas *tin-free steel* (TFS) relies on the inclusion of chromium or aluminum in place of tin. Steel is manufactured into the traditional *three-piece* construction can, which includes a base, cylinder, and lid, and also a *two-piece* can, consisting of a base and cylinder in one piece without a seam and a lid. The latter are lightweight and stackable. Ninety-six percent of the close to 27 billion cans used annually in the United States are made of steel (4).

In addition to steel cans and trays, more than 25 billion beverage bottles crowns (closures with crimped edges) made of steel are used annually in the United States (4). The five primary types of steel vacuum closures include side seal caps, lug caps, press–twist caps, snap-on caps, and composite caps (Figure 19.3).

New microwavable steel cans are available for packaging. Steel cans that are capable on running on a manufacturer’s steel can filling lines are now also capable of microwave heating by the consumer. This is due to new developments in steel can technology. A plastic end is attached to a steel can body, allowing microwave energy to pass through and heat the product. The plastic end is a multilayer polypropylene. The can has a plastic overwrap and an insulating foam label keeping the microwaved can cooler than traditional plastic bowls, and thus, of benefit to the consumer. (Ball Corporation)

In some case, *retort packaging* may provide more consistent flavor and texture than food in cans. The requirement on film used in retort packaging is that it must hold up to varied thermal processing, and the subsequent processes of distribution and storage. Some #10 cans may replaced by large sized pouches that hold 128 oz. of food.

Aluminum is formed easily into cans with hermetic seals. It also is used in trays and for wraps such as aluminum foil, which provide an oxygen and light barrier. It is lighter in weight than steel and resists corrosion.

Glass

Glass is derived from metal oxides such as silicon dioxide (sand). It is used in forming bottles or jars (which subsequently receive hermetic seals), and thus protects against water vapor or oxygen loss. The thickness of glass must be sufficient to prevent breakage from internal pressure, external impact, or thermal stress. Glass that is *too* thick increases weight, and thus freight costs, and is subject to an increased likelihood of thermal stress or external impact breakage.

Technological advances in glass packaging have led to improvements in strength and weight, as well as color and shape. A resurgence of glass may be noted on supermarket shelves. The product is commercially sterile (see Chapter 16), yet the see-through glass tends to denote "fresh" to the consumer. Glass coatings, similar to eyeglass coatings of silicons and waxes, may be applied to glass containers in order to minimize damage-causing nicks and scratches.

Paper

Paper is derived from the pulp of wood and may contain additives such as aluminum particle laminates, plastic coating, resins, or waxes. These additives provide burst strength (strength against bursting), wet strength (leak protection), and grease and tear resistance, as well as barrier properties that assure freshness, protect the packaged food against vapor loss and environmental contaminants, and increase shelf life.

Varying thicknesses of paper may be used to achieve thicker and more rigid packaging.

- *Paper* is thin (one layer) and flexible, typically used in bags and wrappers. Kraft (or "strong" in German) paper is the strongest paper. It may be bleached and used as butcher wrap or may remain unbleached and used in grocery bags.
- *Paperboard* is thicker (although still one layer) and more rigid. Ovenable paperboard is made for use in either conventional or microwave ovens by coating paperboard with PET polyester (see Plastic).
- Multilayers of paper form *fiberboard*, which is recognized as "*cardboard*."

When packaging serves as a *primary* container for food, it is a food-contact surface and must be coated or treated accordingly. For example, *paper* bags or wraps for bakery products may be laminated to improve burst or wet strength, grease and tear resistance, or prevent loss of moisture. *Paperboard* may be lined and formed to hold fluid milk. It may be formed into canisters with foil linings and resealable plastic overwraps, to provide convenience, protection and extended shelf life. *Corrugated* paperboard may be waxed in order to package raw poultry contents.

Dual-ovenable trays are designed to be microwaveable and able to be placed in a *conventional* oven. As with all new processing and packaging technology,

FIGURE 19.1 An example of fiber-wound tubes (*Source*: Sara Lee Corporation).

the use of these trays is a new concept for many people and may require written consumer education by food manufacturers.

Recycled papers may contain small metal fragments that could be unacceptable in packaging used for microwave cooking. The sparks generated as the microwaves are reflected by metal may start a fire in the microwave oven. Yet, paper may be manufactured to designated specifications and deliberately contain areas with small particles of aluminum, which form a "*susceptor*."

Susceptors are desirable for browning and crisping microwaveable foods such as baked goods, french fries (often placed in individual compartments of a susceptor), and pizzas. They are used in packages of microwaveable popcorn, for example, because the metal reflects microwaves, which subsequently heat the surface of the food. New packaging applications include frozen fries.

When used in combination with metal, such as aluminum, paper may be used to produce fiber-wound tubing. An example of fiber-wound tube containers used for refrigerated biscuits is shown in Figure 19.1.

Metallized films and papers increasingly are chosen for food applications. The appearance and its barrier properties to grease and moisture are desirable for packaging specific foods. These materials contain plastic, which is discussed in the following chapter section.

Plastic

Plastic has shrink, nonshrink, flexible, semirigid, and rigid applications, and varies in its degree of thickness. Important *properties* of the many types of plastics that make them good choices for packaging material include the following:

- Flexible and stretchable
- Lightweight
- Low-temperature formability
- Resistant to breakage, with high burst strength
- Strong heat sealability
- Versatile in its barrier properties to O_2, moisture, and light

Basic hydrocarbon building blocks such as ethane and methane, which are derived from natural gas and petroleum, form organic chemical compounds called *monomers*. These are then chemically linked to form plastic molecular chains, or *polymers*. Their manufacture represents 1.5% of total US energy consumed (5). Plastic has multiple *functions* as a packaging material, including use in bottles and jars, closures, coatings, films, pouches, tubs, and trays (1). It also may be used *in combination* with other packaging materials such as metal (for lining cans), paper (for moisture resistance), and glass (reduces bottle breakage).

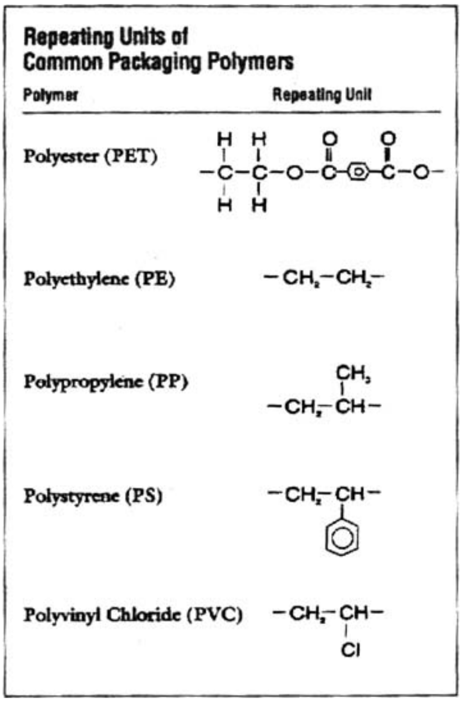
Favorable views of plastic have developed as it was found that approximately 400% more material by weight would be needed to make packaging if there was *no* plastic (6), and that for every pound of plastic packaging that was used, 1.7 pounds of food waste were prevented (7). Additionally, *plastic grocery bags* require approximately 40% less energy to make than paper bags (8), and plastic bag packaging contributes up to 80% less solid waste by volume than paper sacks (9). It takes less than one-fourth pound of 2-liter plastic bottles to deliver 1 gallon of beverage, whereas it takes 4.3 pounds of 16-ounce glass bottles to deliver that same 1 gallon (8).

Choices of Plastics for Packaging. The food industry must provide packaging with barrier protection (against moisture, light, air, grease, etc.) and must "know what level of barrier performance is sufficient for the goods they are packaging" (10). *Insufficient* packaging, attributable in part to a high cost of materials, is not satisfactory, and *too much* performance (excesses in packaging contribution), with excessive barrier protection, is unnecessary.

Among the thousands of types of plastics that are created, less than two dozen are polymers utilized in food packaging (see Table 19.1). Some of the more commonly used plastics for food products are discussed in the following:

Polyethylene (PE): **Polyethylene** is the most common and the least expensive plastic comprising 63% of total plastic packaging. It is a water-vapor (moisture) barrier and prevents dehydration and freezer burn. An example of the

TABLE 19.1 Example of the Repeating Units of Common Packaging Polymers



Source: The Society of the Plastics Industry.

polyethylene pellets used in producing plastic, such as plastic bags, "zipper" seals, and plastic storage containers, is shown in Figure 19.2, and a view of the film coming off of the die is seen in Figure 19.3. Use of this PE may be recommended for less plasticizer migration into food.

Polyethylene with ethyl vinyl acetate (EVA) creates "freezer wrap," which offers moisture-loss protection without getting brittle in low temperatures. Polyethylene terephthalate (PET) is used in "an increasing number of food and beverages" (11), including use as a tube which dispenses food. Some advantages of PET is that it with stands high temperature foods and is lighter in weight than the glass that it replaces. Polyethylene naphthalate (PEN) received FDA approval in 1996 for use in food packaging. It provides a barrier against gas, moisture, and ultraviolet light. As bottled beverages, including waters, teas, and juices, continue to appear in the marketplace, the use of plastic bottle containers made of PET and PEN may be increasing.

Polypropylene (PP): Polypropylene has a higher melting point and greater tensile strength than polyethylene. It often is used as the inside layer of food packages that are subject to higher temperatures of sterilization (eg, retort pouches or tubs).

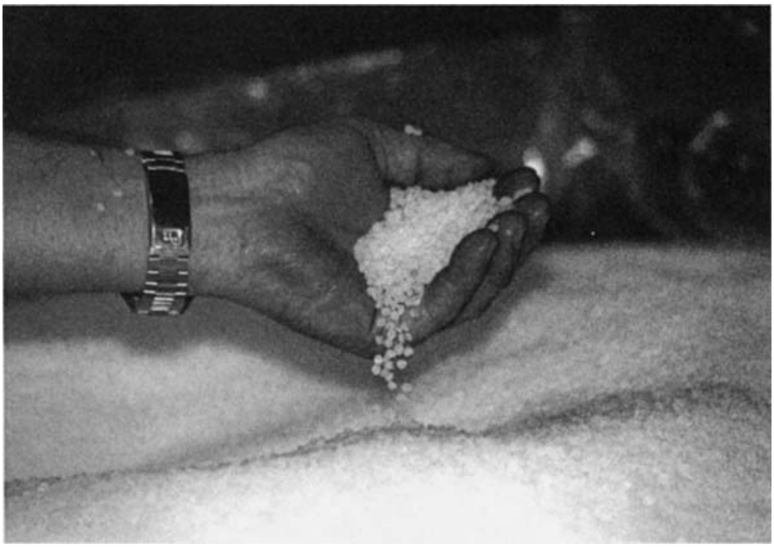


FIGURE 19.2 Polyethylene pellets (*Courtesy*: Rodeo Plastic Bag and Film, Inc., Mesquite, TX).

Polystyrene (PS): ***Polystyrene*** is a versatile, inexpensive packaging material and represents 8% of total plastic packaging. When foamed, its generic name is expandable polystyrene (EPS). This styrofoam has applications in disposable packaging and drinking cups. It offers thermal insulation and protective packaging. EPS is used in “clam shell” fast-food packaging, egg cartons, bowls,

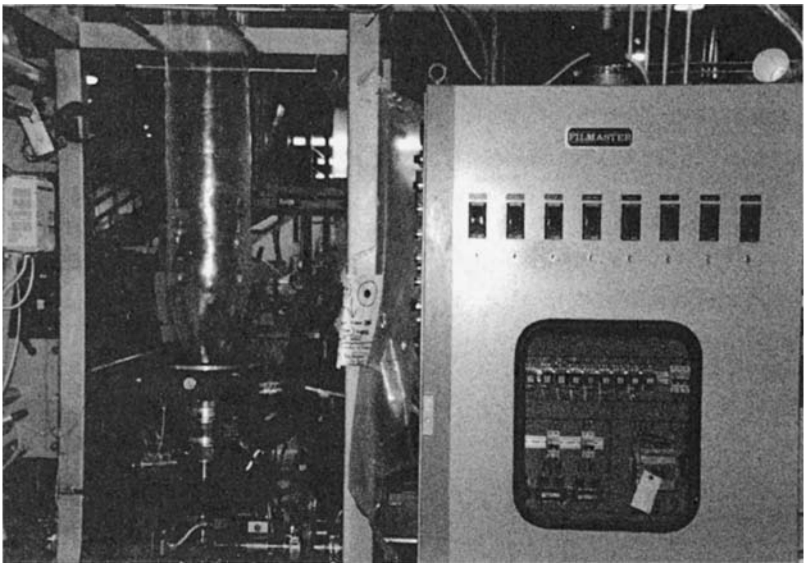


FIGURE 19.3 Blown film bubble coming off the die (*Courtesy*: Rodeo Plastic Bag and Film, Inc., Mesquite, TX).

cups, and meat trays and is the "peanuts" in packages. Approximately 30% less energy is required to form polystyrene cups than paperboard cups (12).

Polyvinyl chloride (PVC or vinyl): ***Polyvinyl chloride*** comprises 6% of total plastic packaging. It blocks out air and moisture, preventing freezer burn, and offers low permeability to gases, liquid, flavors, and odors. PVC prevents the transfer of odor and keeps food fresh by controlling dehydration and is capable of withstanding high temperatures without melting. PVC has good puncture resistance and "cling" properties. It is used to prevent splattering in microwave food preparation.

Polyvinylidene chloride (*PVDC*, Saran®): ***Polyvinylidene chloride*** is a thermoplastic resin used for household wraps and has excellent barrier properties. *Cryovac* is a Saran film used in vaccum-sealing (*Kryos* = cold *Vacus* = empty in Latin).

Many manufacturers specify proprietary molded and shaped bottles to hold the food contents. The appropriate plastic may be chosen to satisfy this highly specialized demand.

There also are *food-based* materials used to produce thermal plastic resins. They are made from natural sugars found in corn and other plants. For example, wheat starch and corn sugar are being developed for packaging purposes. As Australia's Cooperative Research Centers' Executive Director has noted, "The materials consist of wheat starch and are blended with other biodegradable materials so they will compost down fully in around 30–60 days" (13).

Other Packaging Materials

Cotton or **burlap** (jute) may be used for grains, flour, legumes, and some vegetables, primarily in transport.

Edible films are subject to FDA approval because they become part of the food. Natural edible films extend shelf life, although for shorter time than synthetic nonedible packaging materials. Edible films are a unique type of packaging material. As stated in a publication of the Institute of Food Technologist's Expert Panel on Food Safety and Nutrition:

> These films are "... defined as a thin layer of edible material formed on a food as a coating or placed (preformed) on or between food components. Its purpose is to inhibit migration of moisture, oxygen, carbon dioxide, aromas, and lipids, etc; carry food ingredients (eg, antioxidants, antimicrobials, flavor); and/or improve mechanical integrity or handling characteristics of the food" (14).

Antimicrobials may be included in films or containers. Antimicrobial activity may be due to the addition of specific substances, radiation, or gas-flushing. Irradiation sterilization of packaging materials may be forthcoming with FDA approval.

Examples of edible films include those used as the sugar shell on individual chocolate covered candies (M&Ms®); casings, such as in sausage; and *edible waxes*, such as those applied to fruits and vegetables. Serving in the role of edible films, the casings "contain" and the waxes function to improve or maintain appearance, prevent mold, and contain moisture while still allowing respiration. As well, food may be coated with a thin layer of polysaccharides such as cellulose, pectin, starch and vegetable gums, or proteins, such as casein and gelatin. Cut, dried fruit pieces are often sprayed with an edible film prior to their inclusion into items such as breakfast cereal (see Active Packaging Technologies).

Bindings may be applied to a food's surface to be an adhesive for seasoning. Other coatings may significantly improve appearance (and reduce microbial contamination) by replacing egg washes and acting as a glaze.

Foil is a packaging material that may be used in snack bags (chips, etc) or as a laminate in aseptic packaging (see Aseptic Packaging). It is used as a wrapping for dry, refrigerator, or freezer storage. It provides a moisture-proof and vapor-proof barrier.

Laminates are multilayers of foil, paper, or plastics that may be utilized selectively according to the specific food packaging need. In combination, the various laminates may provide more strength and barrier protection than the individual laminate material. Laminates provide barriers useful in controlling O_2, water vapor, and light transmission and they provide good burst strength. The laminates may resist pinholes and flex cracking. Retort pouches are examples of laminates used in packaging and contain polyester film, aluminum foil, and polypropylene.

Resins are used for sealing food packages. They must withstand the stress of processing and offer seal integrity that prevents product contamination.

Wood may be used in the manufacture of crates that contain fresh fruits and vegetables.

Bag-in-a-box is now offered in five-gallon bags with snap-on caps over a 1″ polyethylene spout. There is a high barrier film, with heat-resistance up to 190 °F.

Regardless of the materials that are selected for use, *source reduction, reuse*, and *recycling* should be important considerations of packaging manufacturers. The food industry challenge is to provide the appropriate materials to accomplish packaging functions at reasonable cost.

CONTROLLING PACKAGING ATMOSPHERE

Reduced *temperature* remains as the primary means of food protection. However, controlling the known elements in the package environment, such as O_2, CO_2, water vapor, and ethylene concentration, also may reduce spoilage and contamination (eg, enzymatic, biological), thus extending shelf life (the time required for a food to become unacceptable from a sensory, nutritional, or safety perspective) (15). A summary of reduced oxygen packaging (ROP) from the FDA appears at the end of this section.

The creation of a packaging environment with little or no oxygen has beneficial applications for the food industry. However, microbiological concerns arise simultaneously. As will be discussed, proper controls need to be in place for reduced oxygen packages.

The function of CO_2 addition in packaging is to inhibit growth of many bacteria and molds. The O_2 maintains respiration and color and inhibits growth of anaerobic microorganisms. Nitrogen (N_2) is used to flush the package and rid it of air (O_2 specifically). Nitrogen also prevents a collapse of the loose-fitting packaging material.

Providing control in packaging is needed by fruits and vegetables. They continue to breathe and require oxygen after harvesting and processing, thus the package must contain oxygen. Yet it needs to be controlled, as *too high* a level causes oxidation and spoilage and *too low* a level leads to anaerobic spoilage. In extending shelf life of fruit, oxygen levels should approximate 5% and carbon dioxide at 1–3% (with refrigeration maintained at temperature-specific levels). Packaging environments must match the respiration rate as closely as possible.

The material that follows will address the internal package environment and modification of gases. The following are the significant manners of controlling packaging atmosphere:

- Vacuum packaging
- *Sous vide* processing
- Flushing the packaging environment with specific, targeted gases
    (1) MAP: one-time modification of gaseous environment
    (2) CAP: continuous modification of gaseous environment
- Cook–chill
- Other active packaging technologies

Vacuum Packaging

Vacuum packaging modifies the atmosphere surrounding the food by removing oxygen, and it extends shelf life. Further explained by the FDA in its 1999 Guidelines for Reduced Oxygen Packaging (ROP), "Vacuum packaging reduces the amount of air from a package and hermetically seals the package so that a near-perfect vacuum remains inside. . . . A highly flexible plastic barrier is used by this technology that allows the package to mold itself to the contours of the food being packaged"(FDA).

With the removal of oxygen, vacuum packaging controls rancidity that occurs with the oxidation of fatty acids. Vacuum-packaging machines are available for small-, medium-, or large-scale production capacity (Figures 19.4 and 19.5) and may be used to successfully package a variety of food sizes and forms such as small cheese blocks, large primal cuts of meat, or liquids.

The procedure used for vacuum packaging is to place the food in a flexible-film, barrier pouch, and put it inside a vacuum-packaging chamber, where oxygen is removed. This creates a skintight package wall and protects against the entry or escape of gases such as air and CO_2, or water vapor. It assures inhibition of

FIGURE 19.4 An example of small vacuum-packaging machinery (*Courtesy*: Multivac, Inc.).

microbial growth that would alter microbial and organoleptic properties such as appearance and odor. Water weight loss and freezer burn also are inhibited with this packaging method. The transparent, vacuum-packaging film allows product visibility from all angles.

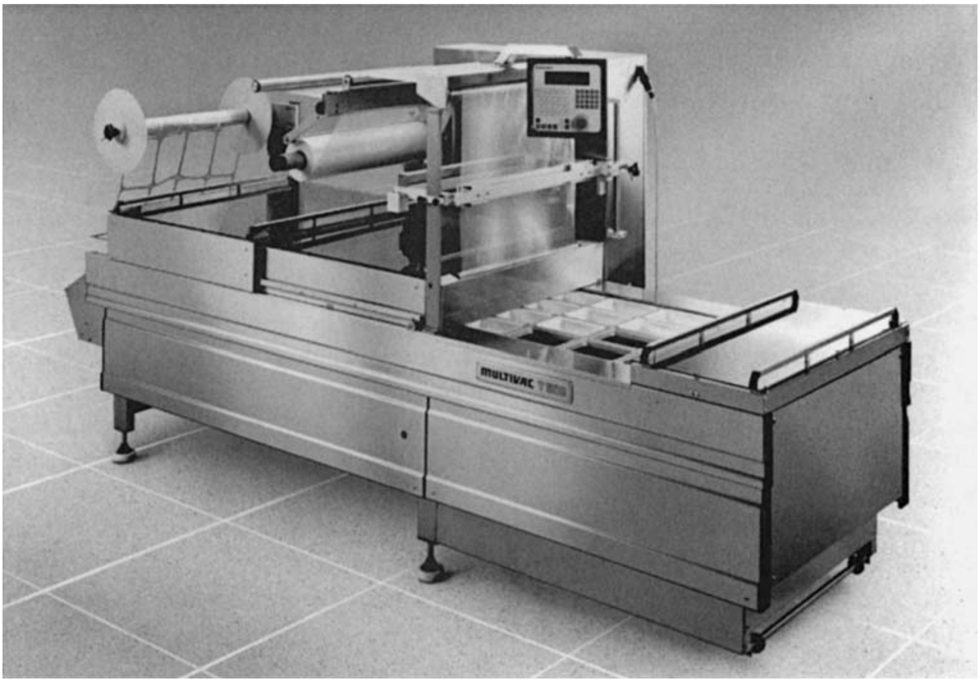


FIGURE 19.5 Large vacuum-packaging machinery (*Courtesy*: Multivac, Inc.).

Controls Needed for Vacuum Packaging. The FDA recommends that local regulatory agencies prohibit vacuum packaging in retail stores unless the following six controls are all in effect:

- Foods must be limited to those that do not support growth of *Cl. botulinum* (as it is an anaerobe).
- Temperatures of 45 °F(7 °C) and below are maintained at all times. Anaerobic pathogens increase their growth rate exponentially with an increase in temperature.
- Consumer packages are prominently labeled with storage-temperature requirements and shelf life.
- Shelf life must neither exceed 10 days nor extend that labeled by the initial processor.
- Detailed, written in-store procedures must be developed, observed, and carefully monitored. These should be HACCP based (Chapter 16) and include records subject to review by regulatory authorities.
- Operators must certify that individuals responsible are qualified in the equipment, procedures, and concepts of safe vacuum packaging.

"Sanitation to maintain a low initial level is thus critical and must be combined with good manufacturing practice to prevent contamination with pathogens" (15).

Sous Vide

Sous vide ("under vacuum") packaging involves mild, partial precooking of food prior to vacuum packaging. Once again, according to the FDA definition in the 1999 Guidelines for ROP, "*Sous vide* is a specialized process of ROP for partially cooked ingredients alone or combined with raw foods that require refrigeration or frozen storage until the package is thoroughly heated immediately before service. The *sous vide* process is a pasteurization step that reduces bacterial load but is not sufficient to make the food shelf-stable." Since *some* of the ingredients may be partially cooked and other ingredients may be raw, the product requires refrigeration or freezing and then heating through prior to service.

The product package has its levels of *oxygen reduced* and CO_2 *raised* in the packaging environment in order to reduce the microbial (aerobic pathogens) load and extend the shelf life. *Sous vide* products are pasteurized but *not* sterile and may contain heat-resistant microorganisms and spores. Therefore, strict temperature regulation in production, as well as in the distribution process, is necessary to assure product safety. Food products must be kept cold to prevent the growth of bacteria (FDA).

According to FDA guidelines, guidelines related to the *sous vide* process include the following:

- Preparation of the raw materials (this step may include partial cooking of some or all ingredients).

- Packaging of the product, application of vacuum, and sealing of the package.
- Pasteurization of the product for a specified and monitored time/temperature.
- Rapid and monitored cooling of the product at or below 38 °F(3 °C) or frozen.
- Reheating of the packages to a specified temperature before opening and service.

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) modifies the internal package atmosphere of food and helps preserve packaged food. It replaces the air in the package with nitrogen or carbon dioxide and the shelf life of the product can increase by as much as 200%. Gas flushing and sealing reduces oxygen coming through respiration of vegetables. MAP is a *one-time modification* of gases so that it is different from air, which normally contains 78.08% nitrogen, 20.96% oxygen, and 0.03% carbon dioxide.

MAP *primarily* is applied to fresh or minimally processed foods that are still undergoing respiration, and it is used for the packaging of a variety of foods. Such foods include baked goods, coffees and teas, dairy products, dry and dehydrated foods, lunch kits, and processed meats (to keep the meat pigment looking desirable). It also is used for nuts, snack food applications, and pasta packaging. This type of packaging with high CO_2 levels inhibits many aerobic bacteria, molds, and yeasts.

MAP is one of the most widely used packaging technologies, as it functions to enhance appearance, minimize destructive waste, extend shelf life, and reduce the need for artificial preservatives. MAP's pure gas or gas mixture environment varies with the type of food and its packaging, temperature, and microbial load. In particular, nitrogen is used in bread products while carbon dioxide is best suited to high-fat products.

Following the packaging of foods, a machine vacuums out *all* of the package air, and then through the same package perforations, *evenly inserts* the new, desired gas combination. Since MAP contains the food under a gaseous environment that differs from air (some other percentage), it controls normal product respiration (consuming O_2 and generating CO_2, water vapor, and perhaps ethylene) and growth of aerobic microorganisms. For example, the change in CO_2 level shows an inhibitory effect on aerobic microorganisms. This effect is dependent on conditions such as the level of CO_2 (a high level in proportion to air is more effective), moisture, pH, and temperature.

The initial mix of packaging atmosphere changes as a result of factors such as product respiration, the aerobic and anaerobic bacterial load, respiration of bacteria, permeation of gases through the packaging materials/seals, temperature, light, time, and so forth (15).

The addition of *nitrogen* gas, which is odorless, tasteless, colorless, nontoxic, and nonflammable, is introduced into the food package *after* all atmosphere has been removed from the pouch and vacuum chamber and just *prior* to hermetic sealing of the package. It increases the package's internal pressure. This modification, by a predetermined dose of liquid nitrogen (LN), offers protection from spoilage, oxidation, dehydration, weight loss, and freezer burn and extends shelf life, as nitrogen consumes oxygen.

Unlike vacuum packaging, the high barrier film (used to keep air out and to prevent the modified atmosphere from escaping) used for MAP remains loose-fitting. This avoids the crushing effects of skintight vacuum packaging. When used in combination with aseptic packaging, which reduces the microbial load, MAP becomes a more effective technology. Most new and minimally processed foods use MAP in combination with aseptic technology and reduced temperature.

Controlled Atmosphere Storage and Packaging

Both controlled atmosphere (CA) in *storage* environments and ***controlled atmosphere packaging*** (CAP) are utilized in order to permit controlled oxygen and carbon dioxide exchange, thus preserving foods. As well, CAP is a prime alternative to pesticides and preservatives. When storage temperatures and conditions of distribution vary in fresh and processed foods, CAP as well as MAP assist in standardizing these variables and maintaining product quality.

The FDA defines CAP as "an active system which *continuously* maintains the desired atmosphere within a package throughout the shelf-life of a product by the use of agents to bind or scavenge oxygen or a sachet containing compounds to emit a gas" (FDA). Controlled atmosphere packaging (CAP) is defined as a packaging of a product in a modified atmosphere followed by maintaining subsequent control of that atmosphere.

However, at any given time and under variable environments there is no continual "control" that the food technologist would describe as "ideal." The question then becomes how much control *is* there in the package environment? Is it then more likely that the atmosphere is *modified?* This form of packaging also utilizes a high barrier film (or pouch), which may be EVOH high-barrier polymers, or Polymid, a form of nylon.

Many packaged food products undergo respiration and microbial growth, requiring oxygen, while producing CO_2 and water. The carbohydrate molecule, in the presence of oxygen, $C_6H_{12}O_6 + O_2$, for example, yields $CO_2 + H_2O + \text{heat}$. Therefore, CA or CAP containers offer control by reducing the available O_2, elevating CO_2, and controlling water vapor and ethylene concentration. The worldwide distribution and marketing of produce depends on CAP for high-quality food. A benefit is that less senescence and maintenance of nutritional value is observed.

C. botulinum is an anaerobic bacterium that grows in the absence of available oxygen. Therefore, it may grow in anaerobic packaging environments. To retard its growth in CAP food products, foods must have short-storage times and be held at cold temperatures. Control of water activity (A_w) and salt also is necessary to prevent growth as sodium competes with the bacteria for water absorption.

Food production has shown a rising use; thus, the demand for various industrial gases such as CO_2 and N_2 has grown. Perhaps this increase in demand may be attributed to more convenient foods, packagings that provide a longer shelf-life, CAP, and MAP.

Of course, MAP itself may not be sufficient. The barrier offered by the packaging is significant. If the material is a poor barrier, then the nitrogen or carbon dioxide will be replaced with the surrounding oxygen due to diffusion. If the packaging offers a good barrier, then the gases will remain in the package for a longer period of time, protecting the product.

Cook–Chill

Cook–chill is defined as a packaging procedure that also results in reduced oxygen levels. By FDA definition it "is a process that uses a plastic bag filled with hot cooked food from which air has been expelled and which is closed with a plastic or metal crimp." Such a system is one that frequently may be employed in hospital food service operations as an alternative to a more conventional food service operation (FDA).

http://www.cfsan.fda.gov/~dms/fcannex6.html shows FDA ruling on ROP

Active Packaging Technologies

Active packaging began as *"smart" packaging* in 1980s, and was referred to as "*interactive*" packaging almost from the start. All three terms describe the same thing, which is packaging that could "sense" changes in the internal environment and respond by adapting as necessary. Sachets may be added to a package in order to control elements such as ethanol, oxygen, or microbes (16).

By its inherent design, packaging typically serves in a *passive* role by protecting food products from the external environment. It provides a physical barrier to external spoilage, contamination, and physical abuse in storage and distribution. Today, packaging more *actively* contributes to the product's development, controls maturation and ripening, helps in achieving the proper color development in meats, and extends shelf life (17). Thus it is considered to play an *active* (not passive) role in protecting foods (13,17). Yet, despite the many attributes and benefits of smart/interactive/active packaging, it generally does not actually "sense" the environment conditions and change accordingly.

Examples of ***active packaging*** technologies are listed in the following text. Active packaging for *fresh and minimally processed* foods provide the following:

- Edible moisture or oxygen barrier (to control loss of moisture and enzymatic oxidative browning in fresh cut fruits and vegetables and to provide controlled permeability rates matched to the respiration rate of the fruit) (Chapters 7,18).

(B) Definitions

The term “ROP” is defined as any packaging procedure that results in a reduced oxygen level in a sealed package. The term often is used because it is an inclusive term and can include other packaging options such as:

(1) *Cook–chill* is a process that uses a plastic bag filled with hot, cooked food from which air has been expelled and which is closed with a plastic or metal crimp.

(2) *Controlled atmosphere packaging (CAP)* is an active system which continuously maintains the desired atmosphere within a package throughout the shelf life of a product by the use of agents to bind or scavenge oxygen or a sachet containing compounds to emit a gas. Controlled atmosphere packaging is defined as packaging of a product in a modified atmosphere followed by maintaining subsequent control of that atmosphere.

(3) *Modified atmosphere packaging (MAP)* is a process that employs a gas flushing and sealing process or reduction of oxygen through respiration of vegetables or microbial action. Modified atmosphere packaging is defined as packaging of product in an atmosphere which has had a one-time modification of gaseous composition so that it is different from that of air, which normally contains 78.08% nitrogen, 20.96% oxygen, 0.03% carbon dioxide.

(4) *Sous vide* is a specialized process of ROP for partially cooked ingredients alone or combined with raw foods that require refrigeration or frozen storage until the package is thoroughly heated immediately before service. The *sous vide* process is a pasteurization step that reduces bacterial load but is not sufficient to make the food shelf-stable. The process involves the following steps:

   (a) preparation of the raw materials (this step may include partial cooking of some or all ingredients);

   (b) packaging of the product, application of vacuum, and sealing of the package;

   (c) pasteurization of the product for a specified and monitored time/temperature;

   (d) rapid and monitored cooling of the product at or below 3°C(38°F) or frozen; and

   (e) reheating of the packages to a specified temperature before opening and service.

(5) *Vacuum packaging* reduces the amount of air from a package and hermetically seals the package so that a near-perfect vacuum remains inside. A common variation of the process is vacuum skin packaging (VSP). A highly flexible plastic barrier is used by this technology that allows the package to mold itself to the contours of the food being packaged.

FDA: Benefits of ROP

ROP can create a significantly anaerobic environment that prevents the growth of aerobic spoilage organisms, which generally are gram-negative bacteria such as pseudomonads or aerobic yeast and molds. These organisms are responsible for off-odors, slime, and texture changes, which are signs of spoilage.

ROP can be used to prevent degradation or oxidative processes in food products. Reducing the oxygen in and around a food retards the amount of oxidative rancidity in fats and oils. ROP also prevents color deterioration in raw meats caused by oxygen. An additional effect of sealing food in ROP is the reduction of product shrinkage by preventing water loss.

These benefits of ROP allow an extended shelf-life for foods in the distribution chain, providing additional time to reach new geographic markets or longer display at retail. Providing an extended shelf life for ready-to-eat convenience foods and advertising foods as "fresh—never frozen" are examples of economic and quality advantages.

FDA: Safety Concerns

Use of ROP with some foods markedly can increase safety concerns. Unless potentially hazardous foods are protected inherently, simply placing them in ROP without regard to microbial growth will increase the risk of foodborne illnesses. ROP processors and regulators must assume that during distribution of foods or while they are held by retailers or consumers, refrigerated temperatures may not be consistently maintained. In fact, a serious concern is that the increased use of vacuum packaging at retail supermarket deli-type operations may be followed by temperature abuse in the establishment or by the consumer. Consequently, at least one barrier or multiple hurdles resulting in a barrier need to be incorporated into the production process for products packaged using ROP. The incorporation of several subinhibitory barriers, none of which could individually inhibit microbial growth but which in combination provide a full barrier to growth, is necessary to ensure food safety.

(1) *Refrigerated Holding Requirements for Foods in ROP*

Safe use of ROP technology demands that adequate refrigeration be maintained during the entire shelf life of potentially hazardous foods to ensure product safety.

- Edible antimicrobial (biocidal) polymer films and coatings (which may release controlled amounts of chlorine dioxide into the food, depending on temperature and humidity; or destroy *E. coli* 0157:H7 in meats, and prevent mold growth in fruits).
- Films that are scavengers of off-odors.
- Oxygen scavengers for low-oxygen packaging.

Active packaging for *processed* foods provides the following:

- Edible moisture barrier.
- O_2, CO_2, and odor scavenger.

Other active packaging technologies include the following:

- Microwave doneness integrators (indicators).
- Microwave susceptor films to allow browning and crispness (french fries, baked products, popcorn).
- Steam release films.
- Time–temperature indicators (TTI), which are unable to reverse their color when the product has been subject to time–temperature abuse

Specifically, the predictability of the behavior of a living, breathable fruit or vegetable, or even meat, is quite different from a nonfood item that is packaged. There are numerous interactions between the food, any internal gas in the package atmosphere, and the material used for packaging. Sachets or films may release their intended effect at a controlled rate. The FDA gave the "go-ahead" for a type of active packaging that releases chlorine dioxide gas to kill harmful bacteria and spoilage organisms (18).

Aseptic Packaging

In order to destroy any *C. botulinum* spores and extend the shelf life of low-acid foods, ***aseptic packaging*** may be utilized (Figure 19.6). Independent sterilization of both the *foods* and *packaging material,* with assembly under *sterile environmental* conditions, is the rule for aseptic packaging which now shows more main stream technology.

In an aseptic system of packaging, the packaging material consists of *layers* of polyethylene, paperboard, and foil (Figure 19.7). It is sterilized by heat (superheated steam or dry hot air) or a combination of heat and hydrogen peroxide and then roll-fed through the packer to create the typical brick/block shape.

The container is filled with a sterile (no pathogens or spores) or commercially sterile (no pathogens, but *some* spores) liquid food product and sealed in a closed, sterile chamber. Once packed, the product requires no refrigeration. Liquids such as creamers, milk, or juices may be packed in this manner. Triple or multiple packs of flavored milk and juice, with attached straws, are available on grocery shelves. The market leaders of aseptic packages have introduced easy-open, easy-pour features into their cartons. The plastic devices are injection molded and adhere to the package tops.

The sterility of packaging material has formerly relied on *chemical* technologies of sterilization (principally heat with hydrogen peroxide). *Nonchemical* techniques have been explored in order to avoid chemical sterilant residues. Ionizing and nonionizing radiation have been tested for use in aseptic packaging.

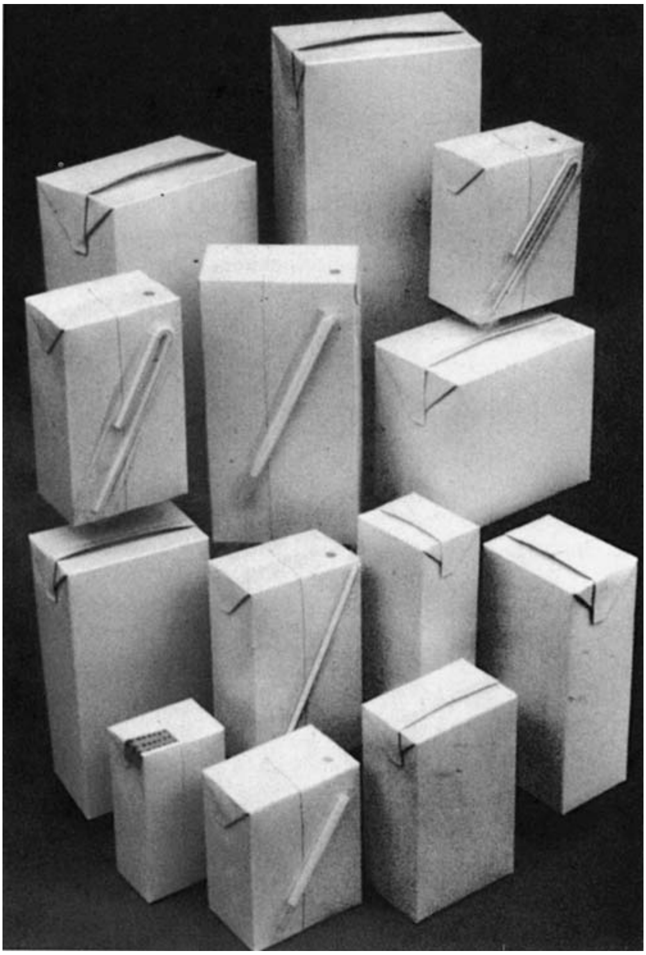


FIGURE 19.6 Different Tetra Brik® aseptic package sizes (*Source*: Tetra Pak Inc.).

Flexible Packaging

Flexible packaging is available for packaging use in the foodservice industry and is finding more applications at the *retail* level, including packaging for bagged cereals and sliced deli meat. Nonrigid packaging containers such as stand-up pouches or tubes and zippered bags are examples of flexible packaging used for peanuts, peanut butter, or produce such as fresh-cut lettuce and peeled baby carrots. The same packaging also might need to be *resealable* to meet consumer demands and may require zipper handles or spouts with *easy open* screw-off tops.

"Flexible packaging uses less material, is more cost effective, and packaging speeds are getting higher. Large flexible packages have replaced cans and rigid packaging." Whether it is attributable to flexible packaging alone, or marketing,

FIGURE 19.7 Tetra Brik® aseptic packaging material layers (*Source*: Tetra Pak Inc.).

and so forth, one manufacturer of snack mix has said "Sales of the product more than doubled just by changing the package" (19).

Flexible packaging is adequate for the plethora of low-fat/no-fat food products such as salty snack foods that are available in the marketplace. It keeps these products fresh by providing flavor and aroma barriers, which keep outside odors out and flavors in. It is used for fresh fruits and vegetables and matches respiration rate as closely as possible.

Manufacturers are offering more food products in flexible packaging and find that "cost savings and environmental concerns are two of the driving forces behind the switch to flexible packaging"(20). "Faster, better, stronger, cheaper…the packaging industry continually tries to improve the process. Nowhere is this more apparent than in flexible packaging" (20).

FREEZER PACKAGING PROTECTION

Freezing foods is a means of preservation (Chapter 17), but foods may spoil due to desiccation or cavity ice if they are not adequately protected. Therefore, a moisture-barrier film, such as a freezer wrap, is needed in packaging material. Tear strength and wet strength also are needed in packaging material for freezer storage.

Freezer Burn

Pronounced desiccation occurs as water diffuses from the product to the atmosphere. This results in ***freezer burn*** with its resultant change in appearance, flavor, texture, and weight.

Cavity Ice

Cavity ice is the ice formation within the food package due to water condensation. Therefore, it is important to use moisture-proof and vapor-proof packaging.

TAMPER-EVIDENT BANDING AND SLEEVE LABELING

Tamper-evident banding and sleeve labeling may assist manufacturers and consumers by providing protection and offering the security that the package contents are unviolated. Today, tamper-evident neckbands and shrink-film sleeves are made in a number of colors and may be custom printed. Technology for full-body shrink-labels over glass and plastic bottles is more apparent, as it has become more affordable and attractive. Pull-tabs and perforations provide ease of use. Figure 19.8 shows the application of tamper-evident banding, and Figure 19.9 provides an example of the tamper-evident banding that has been applied to a container. While the majority of rigid packaging includes tamper-evident attributes, not all food is packaged in this manner. Considering security issues, bakery and dairy products may be especially susceptible (21).

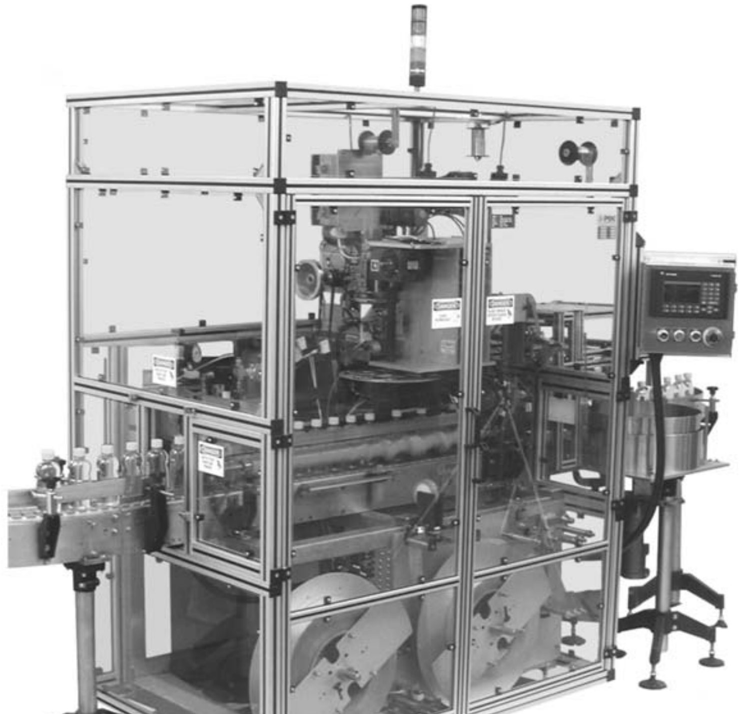


FIGURE 19.8 Example of machinery applying a tamper-evident band (*Source*: PDC International Corporation).

FIGURE 19.9 An example of a tamper-evident band (*Source*: PDC International Corporation).

MANUFACTURING CONCERNS IN PACKAGING

Selection of Packaging Materials

Environmental conditions in package transport and government regulations may dictate the materials a company uses in shipping food containers domestically or overseas. Many components of the food industry demand that packaging material is biodegradable, recyclable, strong, and waste-to-energy efficient. The food processor must choose materials that effectively preserve shelf life and are environmentally friendly and affordable. The packaging material needs to meet all criteria of shipment, labeling, marketing, and other purposes of packaging.

Migration from Packaging Materials

The packaging industry recognizes that the migration of substances from the packaging into the food *could* be harmful to the consumer or have an adverse effect on the acceptability of the food. Therefore, compliance with limits set on migration of packaging materials and control of additives at the point of manufacture is ensured.

Plastics have a greater likelihood of imparting their "plastic taste" and odor to a food than paper. They may contain many additives, including antioxidants, antistatics, plasticizers (to improve the flexibility of some "cling" films), and stabilizers to improve the functional properties of the plastics. Although there has been no report of danger to human health from plasticizer additives, the plastics industry has reformulated some grades of films that contain plasticizers and continues to offer polyethylene plastic wraps with low levels of plasticizers

The FDA has responded to the stories about the dangers of chemicals leaching from plastics into microwaved food. Any plastic used as a "food contact surface" needs FDA approval that it is safe for its intended use (usefulness and harmlessness) prior to being approved for use. According to the FDA, "It's true that substances used to make plastics can leach into food. But as part of the approval process the FDA considers the amount of a substance expected to migrate into food and the toxicological concerns about the particular chemical." While the FDA finds that levels of migrating material are well within the established margin of safety, the issue continually will be reevaluated in light of new materials or new data (FDA).

Diethylhexyl adipate (DEHA) commonly is used in polyvinyl chloride (PVC) food wrap as a platicizer. PVC does *not* use the platicizer with phtalates. A close analysis of DEHA indicated *no* toxic affect in animal studies. It is *approved* as a food contact surface.

Migration from packaging materials is more likely to occur at high temperatures with fatty foods; therefore, industry packaging of microwave foods is designed to be safe for microwave use at high temperatures. *Consumers* who use packaging films for cooking or reheating in the microwave should be aware that "microwave-safe" criteria may not be established for packaging films that can have direct contact with food during reheating in a microwave. Therefore, using *glass* containers may be preferable choices for microwave reheating.

The use of recycled plastics and paper reduces control over contaminants that may be in the secondhand materials. Further research on the use of recycled materials must be conducted and brought forth, before it is recommended that recycled materials be used in food-contact applications (due to the possible migration of contaminants).

There is another concern regarding *dioxins* in plastic food wrap. According to the FDA, a concern for *dioxins* in plastic is not warranted. "The FDA has seen no evidence that plastic containers or films contain dioxins and knows of no reason why they would" (FDA). In addition to plastics, the printing *ink* on the package must be controlled, as it too imparts undesirable flavor to packaged food and may stain the surface of material it contacts while hot (ie, microwave oven).

Packaging Lines at Processing Plants and Food Service Operations

Packaging lines at processing plants may operate efficiently or be down and hold up production. When correctly managed and automated, computer-controlled production lines drastically increase the speed and productivity of many packaging machines, yet the repair of troubled computer-controlled production lines requires significant expertise. Manufacturers' use of poor-quality bottles, boxes, films, labels, and other materials may result in line stoppages which could result in reduced product quality if longer than expected holding of heat-sensitive ingredients is required (22).

Polyester films may be used to wrap dual-ovenable trays for meal delivery in some institutional food service settings such as schools. In the case of one institutional meal provider, serving almost 10 million meals per year, there was difficulty with the removal of heat-seal film from trays in cleanup operations. As a result, specially designed films were developed (23).

Survey of Important Issues in Food Packaging

A survey of food industry participants responsible for packaging (24) reveals that the three top issues in food packaging include product safety, consumer convenience, and product shelf life. They are the primary concern to 80, 73, and 70% of respondents, respectively. *Environmental concerns* and *cost of materials* continue to be important issues (24). As mentioned, the use of food materials in packaging is possible and it assists manufacturers in becoming more environmentally conscious. Another major concern of survey respondents is automation of their machinery to give better handling and reduce labor costs.

A 1996 *Packaging Digest* survey reports that 95% of consumers rank the preservation of flavor and taste as the most important role for food packaging. Value for the money ranked second. More than 8 out of 10 wanted tamper-evident packaging (3).

PACKAGING OF THE FUTURE

Packaging offering single servings for toddlers through teens, working adults, to seniors in health care has multiplied in recent years. For example, older Americans, who may exhibit a decreased manual dexterity, benefit from the use of more simple screw tops on tabletop liquid food containers.

It may all be relative to the day and age in which consumers live, but convenience is a desirable attribute of food and its packaging. In a recent year, there were over 14,000 new food and beverage introductions, many to provide convenience. The introduction of microwaveable, push tube, or push-ups, for example, now represent a new packaging category of convenience. It can be assumed only that the future will contain many more packaging advances in order to supply convenience to the consumer. A look at some predictions for packaging of the future is provided in the following subsections.

Paperboard

Paperboard packaging of the future may offer more benefits to the consumer and retailer. When surveyed by the Paperboard Packaging Council (PPC) and the Institute of Packaging Professionals, packaging experts responded with some innovations that might be just a few years away. The five top predictions for the paperboard packaging of the future are that paperboard packaging might contain the following:

- Temperature sensors: to indicate doneness on consumer foods such as meals.

- Freshness sensors: using colors that change or displaying warnings to indicate when a product is no longer safe to consume.
- Pilferage protection: by mini, antitheft computer chips built into bar codes on paperboard cartons.
- Holographics: used on paperboard packaging material for merchandising. Holographic effects are achieved by the utilization of an embossable metallized film combined with paperboard in a specially designed process.
- Taking cartoons: by the use of computer voice chips a box can talk to consumers (25).

The Association of Industrial Metallizers, Coaters and Laminators (AIMCAL) has given many technical and marketing awards to food packaging with holograms.

Future packaging ideas include packaging that eliminates the need for inner bags in ready-to-eat cereal boxes. Considerations for the acceptance of this packaging type include barrier protection, recycle ability, printability, and ease of use. In Europe, such packaging ideas include *performa barr* (26), a bleached sulfate board with a core of CTMP (chemothermomechanical pulp), which provides package bulk and stiffness. It consists of a clay outside coating that affords printability and an inside coating of three-layer plastic. The inside coating composite includes (1) oxygen and aroma barrier protection, (2) sealability and moisture resistance, and (3) a middle layer that is designed to hold the composite together. Once developed, uses may expand to other foods.

Aseptic and Modified Atmosphere Packaging Combinations

Together, aseptic and modified atmosphere packaging, two popular forms of packaging, may reduce microbial load (by heating the product) and make MAP a more effective treatment:

> "...the two categories, not labeled as such for consumers to identify, continue to grow because their results fit contemporary consumer demand. The fact that the two seemingly unrelated technologies are being integrated to complement each other should suggest that we have entered into a new era of food science and technology in which disparate disciplines are—and must be—combined to synergistically achieve the optimum outcome of quality, convenience, and safety in our food supply" (27).

Organizations Packaging Survey

Another survey was given by *Food Engineetring* journal to its readers. Unlike the survey reported earlier, this was a packaging trends survey that covered 24 food packaging issues. Results showed that organizations have increased their investment in packaging, both *packaging style* and *substance* (FE). Money has gone to robotics as well. In fact, food and beverage are one of the fastest growing segments of robotics and it is the packaging departments that have the most robotic machinery. This includes palletizers, case packers, and carton formers.

Product safety formely had been No. 1 but moved to No. 2, replaced by concern for material costs. Many survey respondents reported that club store demands were a growing operational concern. (see RFID tags)

"Green" concepts such as environmentally friendly sustainable packaging continues to be addressed. However, when asked to rate nine factors for developing new packaging, *source reduction* was last among issues affecting business concerns. *Recycling and material recovery* did better. (28)

RADIO FREQUENCY IDENTIFICATION TAGS

Packaging may contain Radio Frequency Identification (RFID) tags (see Chapter 20). RFID is more than an inventory or packaging/labeling technology as it assists manufactures and users track packaged food throughout the supply chain. Although it may be required (mandated) of vendors delivering to suppliers, such as major food clubs, trials still are ongoing at this point. Currently, readability rates, tag costs and availability, tag application, accurate customer recording, and other problems exist with the use of this new technology. RFID rated 18 out of the 24 issues of most significance to readers (28).

PACKAGING AS A COMMUNICATION AND MARKETING TOOL

Packages contain and protect food during storage, shipment, and sale, and serve other functions, as discussed, such as provide convenience and utility of use. They also *communicate* important consumer information on their labels (Chapter 20). For example, information regarding ingredients, nutrition facts, manufacturers' name and address, contents weight, bar coding, and so forth appear on package labels. The food processor must be aware of worldwide differences in acceptability of packaging format, including use of colors and picture symbols, before a product is marketed in another culture.

Packaging serves as a *marketing tool*. The package and label design are significant in attracting potential customers and many labels may carry recipes, coupons, mail-in offers, or announcements of special upcoming events. It may be that a change in packaging greatly increases sales. Yet changes must not confuse consumers who have built product loyalty by familiarity over the years. For example, milk cartons may not be readily accepted if changed, yet a difference in packaging material, such as cereal without a cardboard box, might be well accepted and profitable.

It is reported by a university marketing professor (26) that consumers use more of a product at a time when it comes in a *larger* package. This may be attributed to (1) the buy-more, use-more phenomenon, as consumers perceive food products as less expensive when purchased in larger quantity (although this is not always true), (2) less concern with running out, and (3) desire to finish the food product as the large size occupies excessive shelf space (29). At the other end of the spectrum, *single* servings of products also are popular in the marketplace.

Product labeling and its importance in product dating, revealing allergens, and so forth has been mentioned. In packaging, paper and perhaps full sleeve, heat shrink PVC labels may be applied to food containers. They offer graphics and assistance as a marketing tool, and provide tamper-evidence, information, and more.

CONCLUSION

Primary, secondary, and tertiary packaging protects raw and processed food against spoilage and contamination while offering convenience and product information to the consumer. A variety of packaging materials, such as metal, glass, paper, plastics, or combinations of these, are used for packaging if they meet with FDA approval.

Packaging films and atmospheres may be selected according to a food product's storage and distribution needs. They may eliminate damaging levels of oxygen, light, and temperature, as well as preventing water-vapor loss, while at the same time protecting the food from spoilage and contamination. Compliance with limits set on migration of packaging materials and control of additives in the materials must be ensured.

Recycling and a variety of packaging technologies, including vacuum packaging, flushing the package with gas, or active packaging, may be used to contribute to effective packaging of food, and more developments loom on the horizon. Packaging of freezer foods requires protection from spoilage. Tamper-evident banding is a protection against external hazards and may be viewed as essential by the manufacturer and consumer. The package label may communicate important information to the consumer serving as a marketing tool. Packaging today provides protection for food products that was unavailable a year ago or even yesterday. More advances are on the horizon.

GLOSSARY

Active packaging: Packaging that makes an active, not passive, contribution to product development or shelf life by such techniques as providing an oxygen barrier or odor and oxygen scavenger.

Aseptic packaging: Independent sterilization of foods and packaging with assembly under sterile conditions.

Cavity ice: Ice formation with the frozen food package due to water condensation and freezing.

Controlled atmosphere packaging (CAP): Controls O_2, CO_2, water vapor, and ethylene concentration.

Flexible packaging: Nonrigid packaging such as stand-up pouches, tubes, or zippered bags.

Freezer burn: Desiccation of frozen food product as the water diffuses from the frozen food to the atmosphere.

Modified atmosphere packaging (MAP): Or gas flush packaging—modification of O_2, CO_2, water vapor, and ethylene concentration by flushing with nitrogen gas.

Polyethylene: Most common, least expensive plastic film used in packaging material.

Polystyrene: Plastic type that typically is foamed to create expandable polystyrene or styrofoam.

Polyvinyl chloride (PVC or vinyl): Plastic packaging film.

Polyvinylidene chloride (PVDC or Saran®): Plastic packaging film.

Primary container: A direct food contact surface as in bottle, can, or drink box that contains a food or beverage.

Secondary container: Does not have food contact, but holds several primary containers in materials such as corrugated fiberboard, boxes, or wraps.

Sous vide: Mild, partial precooking to reduce the microbial load, followed by vacuum packaging to extend the shelf life.

Tamper-evident banding: Sleeves or neckbands providing protection and offering security by indicating evidence of tampering with the product.

Tertiary container: Holds several secondary containers in corrugated fiberboard boxes, overwraps, and so forth.

Vacuum packaging: Removes all atmosphere from the pouch and creates a skintight package wall.

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PART VIII

Government Regulation of the Food Supply

CHAPTER 20

Government Regulation of the Food Supply and Labeling

INTRODUCTION

Consumers want the assurance that they are receiving a safe and sanitary food supply. They want deceptive claims and fraudulence to be nonissues for them to face in everyday life. Therefore, for centuries, governments throughout the world have regulated the food supply. Federal, state, and local government, their regulation, and the educational materials they offer assist in providing a safe food supply.

One of the major regulatory agencies protecting the food supply is the Food and Drug Administration (FDA). Their basic purpose is to protect the public from foodborne illness (Chapter 16), and FDA regulations known as good manufacturing practices (GMP) are in operation at food plants. Of course, maintaining plant sanitation and food safety are ongoing duties of the food processing plant's own personnel.

The FDA Code of Federal Regulations (CFR) is cited several times in this chapter, with the hope of better portraying and understanding the government ruling on an issue.

Interstate transport of food, food packaging, and labeling are regulated, and grading standards and ordinances that specify sanitation for the food environment are enforced. *Intrastate* transport is regulated by each state's Department of Agriculture which may adopt their own, more strict regulations.

The United States Department of Agriculture (USDA) has responsibility for inspecting animal products, including meat, poultry, eggs, meat, and poultry processing plants, as well as voluntary grading. In addition to the government's regulation of the food supply, *industry plants* and *consumers* must be vigilant and play their part in assuring a safe food supply.

THE FOOD AND DRUG ADMINISTRATION

The FDA is a public health agency. The agency regulates 25 cents of every dollar spent annually by American consumers—over $1 trillion worth of products (FDA) and does so at a taxpayer cost of several dollars per individual. The FDA inspects food (ensuring that it is safe and wholesome), cosmetics, medicines and medical devices, radiation-emitting devices (such as microwave ovens), animal feed, and drugs.

FDA Federal Food, Drug and Cosmetic Act—1938

The FDA's Federal Food, Drug, and Cosmetic Act of 1938 (FD&C Act) is the main law that regulates the food supply in the United States. Since the origin of this law, there have been numerous amendments. It replaced the 1906 Federal Food and Drug Act, or "Pure Food Law," and is assigned to regulate many packaged or processed food products. This regulation includes adequate and truthful labels if the food is subject to import or interstate commerce. Additionally, a federal code of regulations is written to cover specific rules for the food industry.

The agency has several thousand researchers, inspectors, and legal staff in approximately 150 cities throughout federal, regional, and local offices in the United States, including scientists (over 2000), chemists (900), and microbiologists (300). Agents of the FDA may work with public affairs or small business as well as laboratory personnel. They interpret law and monitor the manufacture, import, transport, and storage of products both prior to and following sale on the market. Products are examined for construction integrity and labels must be truthful.

Some of the varied activities of federal FDA agents include advising state and local agencies in general duties and prevention of disasters. The FDA has both a regulatory arm of enforcement and cooperative programs of partnership with industry. The latter, for example, helps train employees in preventing foodborne illness. Despite budgetary constraints and a transition of the FDA to a hazard analysis critical control point focus (Chapter 16), the role of this government agency remains to protect the public.

Voluntary correction of public health problems is necessary, but when warranted, *legal sanctions* may be brought to bear against manufacturers or distributors. Recalls of faulty products generally are the fastest and most effective way to protect the public from unsafe products on the market.

Amendments to the Food, Drug, and Cosmetic Act

Several major amendments to the Food, Drug, and Cosmetic Act that were introduced and became law include the following:

- *1954 Pesticide Chemical Amendment*: The use of pesticides is subject to FDA approval. Raw agriculture products are prohibited from containing pesticide residues above a certain level.

- *1958 Food Additives Amendment*: With this amendment, the burden of proof for usefulness and harmlessness of an additive was shifted to industry. Exempt from this proof were generally recognized as safe (GRAS) substances already in common use with no proof of cancer (see GRAS substances, below).
- T*he Delaney Clause* (1966) of the Food Additives Amendment states that an additive (Chapter 18) *cannot* be used if it leads to cancer in man or animals or if the carcinogen is detectable by any appropriate test.

  In recent years, a much-debated question on the necessity of the Delaney Clause has arisen. For example, what *is* an appropriate test to determine the level of a food additive that induces cancer? Finer detection of minute amounts of agents responsible for cancer has become available. Thus, the question is: At what level is the presence of a carcinogen indicative of the need to remove that item from the food supply? There is *no* food item that is, or can be, totally safe at any level of ingestion (even too much *water* has landed people in the hospital!). The future will offer more debate and regulation of this matter.
- *1960 Color Additives Amendment* (Chapter 18): The use of food colors is subject to FDA approval.
- *1966 Fair Packaging and Labeling Act*: Requires all consumer products in interstate commerce to contain accurate information on the package, facilitating better control of misinformation. Consumers benefit in that they can use the label information on packages in making purchasing and value comparisons.
- *1990 Nutrition Labeling and Education Act* (NLEA) was passed by Congress and the FDA then wrote regulations for compliance covering extensive labeling changes, including mandatory nutrition labels, uniform use of product health claims, and uniform serving sizes.

This was an attempt to protect the consumer against misinformation and fraud. New “nutrition facts” labels appeared on food products in May of 1994.

GRAS Substances

Generally recognized as safe substances (GRAS), according to the General Provisions of the Code of Federal Regulations, Title 21 (21CFR582), Sec. 582.1, are discussed as follows:

> “It is impractical to list all substances that are generally recognized as safe for their intended use. However, by way of illustration, the Commissioner regards such common food ingredients as salt, pepper, sugar, vinegar, baking powder, and monosodium glutamate as safe for their intended use.”

Standards For Interstate Transport of Food

The FDA has mandatory standards, identified in the following:

- ***Standard of Identity***. The FDA describes food and lists both required and optional ingredients that are included in manufacture. Examples of products that follow a Standard of Identity included foods such as mayonnaise, white bread, and jelly.

  When initially introduced as law, a food product followed a Standard of Identity in its manufacture, and many required and optional ingredients were *not* listed on labels, as it was understood that the consumer was familiar with ingredients that composed basic foods. In time, however, it became apparent that this familiarity with foods was not widespread. As a result, after 1967, *optional* ingredients of foods were *required* to be included on labels, even if the product followed the Standard of Identity. A standard was continually reviewed and revised as new additives are approved for food use.

  Currently, manufacturers are *required* to state *all* ingredients on the product label, including required and optional ingredients. This change to the complete identification of food ingredients benefits consumers who are unfamiliar with food ingredients that make up a food, as well as those with food allergies or intolerances.
- ***Standards of Minimum Quality***. The FDA states the minimum quality standards for specific characteristics in a food, such as color, defects, and tenderness. (Color, tenderness, blemishes, clarity of liquid, and product size are some of the criteria used at the wholesale and retail level for evaluation.) A food must state “below standard in quality” if the minimum level of a particular quality descriptor is not obtained. For example, we see processors of canned vegetables and fruits follow this standard. Substandard does not signify safety hazards.
- ***Standard of Fill of Container***. This FDA standard ensures that the headspace/void volume of packaged food offered for sale does not interfere with the *weight* of the product as stated on the label. It assures that the product offers the correct weight even if the package is only partially full. For example, packages of cereal, crackers, and potato chips may not appear full due to extra airspace in the package that is needed to prevent food breakage, yet this fact is taken into account and the food is sold by the *weight, not* by the *volume*. Food products packed in a liquid medium, such as canned fruits or vegetables, must contain the stated weight of the product.

Adulterated and Misbranded Food

Adulterated and misbranded foods are defined as follows: *Adulterated* food may *not* be offered for sale. According to the watchful eye of the FDA, a food is adulterated if it:

- Is poisonous or harmful to health at detrimental concentrations.
- Contains filth or is decomposed.

- Contains a food or coloring agent that is not approved or certified.
- Was prepared or packed under unsanitary conditions, making it contaminated.
- Is derived from a diseased animal.
- Contains any excessive levels of residue.
- Was subject to radiation, other than where permitted.
- Has any valuable constituent omitted.
- Substitutes a specified ingredient with an unspecified ingredient.
- Is damaged or conceals defects.
- Is increased in bulk weight or reduced in its strength, making it appear better than it is.

According to the FDA, food is *misbranded* if it:

- Is labeled falsely or misleadingly.
- Is offered for sale under the name of another food.
- Is an imitation of another food, without stating "imitation" on the label.
- Is packaged (formed or filled) so as to be misleading.
- Fails to list the name and address of the manufacturer, packer, and distributor, and a statement of net contents on the label.
- Fails to declare the common name of the product and the names of each ingredient or has label information that is not legible and easily understood.
- Is represented as a food for which there is a Standard of Identity but the food does not conform with an accurate statement of quantity or ingredients.
- Is represented to conform to a quality standard or to a fill of container and does not conform.
- Is represented with a nutritional claim or for special dietary use but the label fails to provide information concerning dietary properties of the food, as required by law.
- Lacks proper nutrition labeling.

The FDA Modernization Act of 1997

The FDA Modernization Act of 1997 (FDAMA) was passed by the Senate and the House and signed into law in 1998. It amends the FD&C Act and the biological products provisions of the Public Health Service Act (PHS Act), with the intent "...to improve the regulation of food, drugs, devices, and biological products, and for other purposes." The act eliminates the FDA's mandatory premarket approval for use of the majority of substances that come into contact with food or may migrate into it. Instead, manufacturers must provide 120 days of notification to the FDA.

Among other sections that address drugs, devices, and biological products, the FDAMA contains nine food petitions as separate sections of the ruling:

- Flexibility for Regulations Regarding Claims—Section 301
- Petitions for Claims—Section 302
- Health Claims for Food Products (authoritative statements, yet not FDA)—Section 303
- Nutrient Content Claims (significant information, 120 days)—Section 304
- Referral Statements (such as "see side panel for nutrition information")—Section 305
- Disclosure of Irradiation (size of statement and use of symbol)—Section 306
- Irradiation Petition (to control food contamination with pathogens)—Section 307
- Glass and Ceramic Ware (regarding FDA's ban on ceramics)—Section 308
- Food Contact Substances (including additives' safety)—Section 309

Additionally, the FDA enforces the Public Health Service Act to maintain sanitary standards at retail foodservice establishments and in milk processing and shellfish operations. The FDA monitors food for safety and wholesomeness on interstate carriers such as planes and trains. The FDA also has a Seafood HACCP (Chapter 16) program, which is aimed at controlling pathogens and foodborne illness from seafood.

A consensus among former FDA commissioner is that the FDA is underfunded and overworked, and that financial resources have been diverted from inspections to drugs. Their concern was that food safety would be relegated to "second-tier management" if the agency was not properly funded or able to enforce regulations.

THE UNITED STATES DEPARTMENT OF AGRICULTURE

The USDA is another major government agency regulating the food supply in the United States. It is responsible for inspection of meat, poultry, agricultural products, including milk, eggs, fruit and vegetables, and meat and poultry processing plants. While the *inspection* service, including bacterial counts, is *mandatory*, the grading service is *voluntary* and is paid for by the manufacturer, marketer, or packer. Accommodations such as a desk, telephone, and parking space should be made available for the USDA inspector who routinely or regularly is present at a plant to assure safe food handling and plant sanitation.

The USDA, or the individual State Departments of Agriculture (states may exceed, but must at least *meet* federal standards), inspects meat, and stamps it with an abbreviation of "Inspected and Passed," containing a number that identifies the plant from which it came. Every carcass but not every cut of meat requires this stamp (made using nontoxic vegetable dye) as proof of sanitary quality and wholesomeness. The stamp is required for shipment in interstate commerce. The label stating “wholesome” indicates that no signs of illness were found, *not* that the meat is free from pathogenic microorganisms.

The Federal Meat Inspection Act of 1906, Federal Poultry Products Inspection Act of 1957, and the Wholesome Poultry Products Act of 1968 are enforced by the Food Safety and Inspection Service (FSIS) of the USDA. The inspection, labeling, and handling of poultry and poultry products are similar to the meat inspection process. Processed poultry products do not undergo a mandatory inspection.

The FSIS conducts activities such as the following to ensure the *safety* of meat and poultry products consumed in the United States:

- USDA inspectors and veterinarians conduct slaughter inspection of all carcasses at meat and poultry slaughtering plants for disease and other abnormalities and sample for the presence of chemical residues.
- USDA conducts processing inspection for sanitation and cleanliness, labeling, and packing at facilities where meat and poultry is cut up, boned, cured, and canned.
- Scientific testing in support of inspection operations is performed by USDA/FSIS laboratory services to identify the presence of pathogens, residues, additives, disease, and foreign matter in meat and poultry.
- Inspection systems in countries exporting meat and poultry products to the United States are reviewed by USDA as part of the import–export inspection system.
- USDA is placing increased emphasis on pathogen reduction and hazard analysis and critical control point (HACCP) in the entire meat and poultry production chain. This involves developing new methods for rapid detection of pathogenic microorganisms, new production, and inspection practices to reduce bacterial contamination, and educating consumers on safe food-handling practices.
- USDA’s Meat and Poultry Hotline is a toll-free service where consumers, educators, researchers, and the media can speak with experts in the field of food safety.

The USDA also has a Food and Consumer Service (FCS) that administers *food assistance* programs such as the following:

- Food Stamp Program
- Food Distribution Program on Indian Reservations and the Trust Territories
- Special Supplemental Food Program for Women, Infants and Children (WIC)
- Farmers Market Nutrition Program
- Commodity Supplemental Food Program
- National School Lunch Program
- School Breakfast Program
- Special Milk Program

- Child and Adult Care Food Program
- Summer Food Service Program
- Nutrition Program for the Elderly
- Food Distribution to Charitable Institutions, Soup Kitchens, and Food Banks
- Nutrition Assistance Programs
- The Emergency Food Assistance Program (TEFAP)

Thus it is seen that there are many USDA Programs. To face the complex nutrition issue in the 21st century, there may be need for researchers, policymakers, and both private and public sector organizations to define and implement a strategy for action agenda. This was the case in the well-known White House Conference on Food, Nutrition and Health in 1969.

Currently there are many nutrition programs, as mentioned, such as the Food Stamp Program, Special Supplemental Food Program for Women, Infants and Children, and so forth. There also are Dietary Guidelines, NLEA, etc, the "building blocks" over the past few decades, yet they do not represent a national nutrition policy (1). Of special note is the USDA "mypyramid.gov " that is reported in this text.

Food Security and An Emergency Plan

"In the aftermath of the September 11, 2001 terrorist attacks on the US, the FDA has urged industry to take necessary steps to ensure better food security. For example, farms, processors, grocery stores and restaurants can better protect the nation's food supply by requiring criminal background checks of all workers, and closely checking all food and water sources. New guidelines were issued by the FDA, and addressed by the ADA."

Bioterrorism Preparedness and Response Act of 2002 ("the Bioterrorism Act")

"The events of Sept. 11, 2001, reinforced the need to enhance the security of the United States. Congress responded by passing the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (the Bioterrorism Act), which President Bush signed into law June 12, 2002. (http://www.fda.gov/oc/bioterrorism/bioact.html)
The Bioterrorism Act is divided into five titles:

- Introduction
- Title I—National Preparedness for Bioterrorism and Other Public Health Emergencies
- Title II—Enhancing Controls on Dangerous Biological Agents and Toxins
- Title III—Protecting Safety and Security of Food and Drug Supply

- Title IV—Drinking Water Security and Safety
- Title V—Additional Provisions

The FDA is responsible for carrying out certain provisions of the Bioterrorism Act, particularly Title III, Subtitle A (Protection of Food Supply) and Subtitle B (Protection of Drug Supply).

"The rule requires domestic and foreign facilities that manufacture, process, pack, or hold food for consumption in the US to register with FDA." (Final rule: http://www.fda.gov/bbs/topics/news/2005/new01236.html)

> "SEC. 305. Registration of Food Facilities
> (a) In General—Chapter IV of the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 341 et seq.) is amended by adding at the end the following:
>
> "SEC. 415. <<NOTE: 21 USC 350d.>> Registration of Food Facilities
> "(a) Registration—
> "(1) <<NOTE: Regulations.>> In general—The Secretary shall by regulation require that any facility engaged in manufacturing, processing, packing, or holding food for consumption in the United States be registered with the Secretary. To be registered . . ."

If the FDA determines that a product poses a serious risk to public health, the FDA Inspectors will submit Form 482c—*Notice of Inspection-Request for Records*—in order to conduct an emergency food contamination inspection. The FDA is allowed to obtain needed records and the form must be submitted in writing to the owner, operator, or agent in charge of the company.

Maintaining business, protecting profits, as well as learning how to recover from disasters are duties of the food plant. Each of these goals must be protected. As mentioned in a recent article "*Building your plant's ark*," "Noah may have been among the first to plan for impending natural disaster. Don't let him be the last" (2).

Developing an emergency plan is "more than putting words on paper. Map out how your plant will react to a variety of disasters: hurricanes, earthquakes, tornados, fires, chemical spills/leaks, terrorism or other potential problems. At the very least, you need an evacuation plan to get workers to a safe location" (2).

The USDA's FSIS now has a Food Biosecurity Action Team (F-BAT). Its intent is to protect agriculture and the food supply, ensure employee safety, have adequate capacity and security at agency laboratories, ensure that essential USDA functions can continue, and to be able to pass on necessary information (to employees, consumers, industry, the media, Congress and other agencies) in a single, consistent message.

Unfortunately, the FSIS has managed many recalls of food products. However, they have decided that during food recalls, distribution lists that usually are confidential, may be made available to state and federal agencies. Such lists would not be subject to public disclosure.

STATE AND LOCAL HEALTH DEPARTMENTS

As mentioned, the *federal* agencies (FDA, USDA) regulate interstate food supplies and it is the task of *state* agencies such as state Food and Drug Administrations and state Agriculture Departments to regulate *intra*state food supplies. In some states, the State Health Department has complete authority over all food operations, whereas in other states, county or city health departments adopt their own food-service regulations.

ADDITIONAL AGENCIES REGULATING THE FOOD SUPPLY

- **The Federal Trade Commission** (FTC) protects against unfair and deceptive advertising practices of products, including food.
- **The National Marine Fisheries Service** (NMFS) of the Commerce Department is responsible for voluntary grading of seafood.
- **The Occupational Health and Safety Administration** (OSHA) regulates health hazards in the workplace (such as food manufacture, processing, or retail food service) and determines compliance with regulations.
- **The Environmental Protection Agency** (EPA) sets environmental standards. This agency regulates air and water pollution by a plant, toxic substances, pesticides, and use of radiation.

GENERAL LABELING

General labeling requires that complete information about food must be supplied on food packages. It must include the following:

- Name of product; name and place of business
- Net weight—ounces (oz), or pounds and ounces
- Ingredients—listed by weight in descending order on ingredients list of label (not Nutrition Facts portion)
- Company name and address
- Product date if applicable to product
- Open date labeling—voluntary types able to be read by the consumer
- Expiration date—deadline for recommended eating (ie, yeast)
- "Best if used by" date—date for optimum quality, QA, or freshness
- Pack date—date food was packaged
- Pull date—last day sold as fresh (ie, milk, ice cream, deli)
- Code date—read only by manufacturer
- Nutrition information—"Nutrition Facts" on nearly all labels
- Nutrient content claims substantiated

- Health claims used only as allowed
- Other information
    - Religious symbols—such as Kosher (if applicable)
    - Safe handling instructions—such as on meats
    - Special warning labels—alcohol, aspartame, which may affect select consumers
    - Product code (UPC)—bar code

More recently, as an example of updates in food labeling and safety, a simpler food labeling bill was introduced to Congress. It is the National Uniformity for Foods Act (HR 4167) and is intended to create national, uniform food safety standards and warnings that would be advantageous for consumers and manufacturers.

According to the Association of Food, Beverage and Consumer Products Companies, "National uniformity is not a new concept—Congress has repeatedly recognized the importance of uniformity in food regulation. The Nutrition Labeling and Education Act (1990), the Food Quality Protection Act (1996), the Poultry Products Inspection Act and the Meat Inspection Act all contain uniformity provisions."

The bill was endorsed by the Grocery Manufacturers Association (GMA): "Regardless of which state they live, all consumers deserve to have the same information about the safety of their foods. By relying on the best science available, the National Uniformity for Food Act will do just that," (GMA Vice President of Federal Affairs). It is opposed by Consumer Union, saying "this bill would eliminate critical state laws that protect consumer health while leaving in place an inadequate federal system based on the lowest common denominator of protection."

The Act passed in late 2005 as House Bill HR 4167 "National Uniformity for Food Act," and went on to the Senate as Senate Bill S.3128.

Radio Frequency Identification Tags

Labels on food products may contain radio frequency Identification (RFID) tags. Some consumer packaged goods, retail operations, transportation, defense, and pharmaceuticals already use RFID. It is more than an inventory or packaging/labeling technology (3). It assists manufacturers and users track packaged food throughout the supply chain. For example, benefits of RFID may include better consumer safety and security and improved operating efficiencies for packaging, manufacturing, distribution, and sales.

As it may be required of vendors delivering to suppliers, training in its benefits and uses may assist users/potential users of the technology. Training can help hardware and software providers and both the public and private sectors, as well as educators and researchers.

NUTRITION LABELING

Food products intended for human consumption are subject to mandatory ***nutrition labeling***, regulated by the FDA. As a result of the Nutrition Labeling and Education Act of 1990 (NLEA), there are regulations that specify information food processors must include on their labels, including "Nutrition Facts". The purpose of the NLEA is the following:

- Assist consumers in selecting foods that can lead to a healthier diet
- Eliminate consumer confusion
- Encourage production innovation by the food industry

NLEA regulations became effective in 1994, and approximately 595,000 food products had to meet these regulations, according to the FDA and USDA.

Consumers benefit from the educational component of the labeling law, as the information on labels is easy to read and may be useful in planning healthful diets. The label provides consumers with consistency under mandatory "Nutrition Facts" which appear on most products offered for sale in the United States. Voluntary information for cuts of meat, raw fish, and the 20 most commonly eaten fruits and vegetables may appear on package bags, brochures, or posters at the point of sale. Labeling values for produce and fish have been revised since initially required, and further revisions will be proposed every 4 years.

The FDA has set 139 reference serving sizes for use on "Nutrition Facts" labels that more closely approximates amounts consumers actually eat than previous labeling. The serving size indicates values, such as the number of ounces in a beverage or the ounces and number of cookies or crackers per serving, the nutrient content of a food is based on this reference-serving size and stated on the label. In packaged food, a food is still labeled as a *single serving* if the amount of food is greater than 50% and less than 200% of the designated single-serving size. Also see the following website: http://vm.cfsan.fda.gov/~lrd/cf101-12.html.

Portion sizes are thus designated by the FDA. Go to www.mypyramid.gov (then go to Inside the Pyramid; Related Topics; View Food Gallery) to see photos of actual foods and portion sizes. Depending on personal intake, the individual nutrient consumption may be more or less than that designated FDA "one serving." (Of course that is acceptable as long as the person who desires to either limit or attain certain nutrients realistically knows what constitutes that "one serving"!) For example, a serving of ice cream is one scoop, not one *bowlful*! The calories, fat, cholesterol, and so forth need to be calculated accordingly. "Portion Distortion" is a name given to a person's mistaken idea *of what equals an actual portion*!

With passage of the NLEA, the FDA set regulations stating that a food label must express nutrient information in terms of recommended daily intake, in grams (or milligrams) or as a percentage, thus the "% Daily Values" or "DV." It shows how a serving of the food fits into a total day's diet.

Two sets of values were included in the establishment of Daily Values. One is the Reference Daily Intakes (RDI), which is based on former "US RDA" (derived from 1968 RDA) labeling values. The second is Daily Reference Values (DRV) for nutrients, such as fat, sodium, cholesterol, and total carbohydrates including dietary fiber and sugars, which do not have an RDA but have a significant health impact. The DV reference values are based on a 2000- or 2500-calorie diet and consumers ingesting more or less calories should adjust numbers accordingly.

Many values are provided on nutrition labels. For example, the total calories and calories from fat, the total fat, and saturated fat (perhaps monounsaturated and polyunsaturated fat if the processor wants to include these), and trans fat are stated. Cholesterol and sodium are stated in milligrams. The total carbohydrate, sugar, and dietary fiber also are reported on Nutrition Facts. Protein is expressed as a quantity that takes into account the completeness of amino acids (complete = having all essential amino acids in the needed amount). Food processors have the option of reporting protein as a % DV on a label, and if they do, they must determine the quality of the protein to ascertain which daily value of protein to use as a comparison.

As mentioned earlier, consumers may be attempting to limit or attain specific quantities of certain nutrients in their diet. For example, a consumer may desire to limit fat or cholesterol; or they may want to increase their intake of vitamins and minerals commonly needed in the United States, such as vitamins A and C, calcium, and iron. A nutrition label can help the consumer know what nutrients are in food.

Examples of terms allowed on food labels appears in Table 20.1. Terms are consistent among products, and manufacturers and food processors must abide by these definitions on their product labels. Yet, when merchandising a product through the various forms of advertisement, there exists no FDA regulation of terms.

In early surveys, conducted several months after implementation of the NLEA, the American Oil Chemists' Society found that 40% of US consumers seldom, if ever, used nutrition food labels in deciding which foods to buy (4). Today, training has attempted to provide more familiarity with the "Nutrition Facts" label, and thus greater use.

The label information intended to assist consumers in making informed food choices, and it did not come cheaply to food processors. The product analyses as well as label redesign and printing costs were incurred. In a survey conducted by the National Food Processors Association it was estimated that $1.28 billion would be spent by the food industry as it implemented NLEA in an 18-month period.

Methods of analyses for nutrition labeling are available to food processors from the AOAC International and the Food Chemicals Codex (FCC). "Whole food" and "ingredient" databases assisted in providing the necessary nutrient information for labels (5). Yet, "even with all the methodology available, food scientists can still be at a loss if they are analyzing a complicated matrix such as canned spaghetti" (6).

In a land of plenty, with an increasing concern of managing personal weight, the USDA has released the 2005 Dietary Guidelines for Americans. They include the USDA and Health and Human Services (HHS) publication which emphasizes both lifestyle and dietary measures for health. Food Technology reports: "So, the news for the food sector is to continue to improve processes and formulations

TABLE 20.1 Some Examples of Terms Allowed on Food Labels

General Descriptive Terms

- *free—negligible amount of the nutrient*
    - good source of—between 10 and 19% of the Daily Value of the nutrient
    - healthy—low-fat, saturated fat, cholesterol, and sodium food with at least 10% of the Daily Value for vitamins A and C, protein, iron, calcium, or fiber
    - low—not meeting Daily Values with frequent consumption
    - high—20% or more of the Daily Values for a nutrient per serving
    - light or lite—one third fewer calories or one-half the fat of the comparison food
    - more—at least 10% more of the Daily Value than a comparison food
    - less—at least 25% or less of a nutrient than the comparison food

Energy/Calories

- *free—fewer than 5 cal per serving*
    - low calorie—40 cal or less per serving
    - reduced calorie—at least 25% fewer calories per serving than a comparison food
    - light—one third less calories than the comparison food

Fat and Cholesterol

- *Fat*
- *fat-free—less than 0.5 g fat per serving*
    - low fat—3 g or less fat per serving
    - percent (%) fat-free—only if low fat or fat-free, calories based on 100-g portions
    - less fat—25% or less fat than a comparison food
    - light—50% less fat than a comparison food

Saturated Fat

- *saturated fat-free—less than 0.5 g of saturated fat and trans fatty acid per serving.*
    - low saturated fat—1 g or less saturated fat per serving
    - less saturated fat—25% or less saturated fat than a comparison food

Cholesterol

- *cholesterol-free—less than 2 mg cholesterol and 2 g or less saturated fat per serving*

TABLE 20.1

- low cholesterol—20 mg or less cholesterol and 2 g or less saturated fat per serving
- less cholesterol—25% or less cholesterol than a comparison food, and 2 g or less saturated fat per serving
- extra lean—less than 5 g of fat, 2 g saturated fat, and 95 mg cholesterol per serving and per 100 g of meat, poultry, and seafood
- lean—less than 10 g fat, 4.5 g saturated fat, and 95 mg of cholesterol per serving and per 100 g of meat, poultry, and seafood

Carbohydrates: Fiber and Sugar

- *high fiber—5 g or more fiber per serving, with 3 g or less of fat per serving (low fat) unless a higher level of fat is specified*
    - sugar-free—less than 0.5 g sugar per serving

Sodium

- *sodium-free—less than 5 mg sodium per serving*
    - low sodium—140 mg or less per serving
    - light—50% less sodium, in a low-calorie or low-fat food
    - very low sodium—35 mg or less per serving

where appropriate, and help consumers avoid foodborne illness and excess, while keeping excitement at the table" (7). Other nations have adopted similar dietary guidelines for their population.

- Feel better today. Stay healthy for tomorrow
- Make smart choices from every food group.
- Mix up your choices within each food group.
- Find your balance between food and physical activity.
- Get the most nutrition out of your calories.
- NUTRITION: To know the facts…
- …use the label.
- Play it safe with food.
- About alcohol.

Dietary Guidelines For Americans

"Dietary Guidelines for Americans is published jointly every 5 years by the Department of Health and Human Services (HHS) and the Department of Agriculture (USDA). The Guidelines provide authoritative advice for people two years and older about how good dietary habits can promote health and reduce risk for major chronic diseases." Current recommendations are found in: www.healthierus.gov/dietaryguidelines.

HEALTH CLAIMS (MORE IN APPENDICES)

In order to make the approved health claims (Table 20.2) a food must contain no more than 20% of the Daily Value for total fat, saturated fat, cholesterol, or sodium, and the food must naturally contain at least 10% of the Daily Value for either vitamins A and C, protein, fiber, calcium, or iron.

Examples of approved health claims appear in Table 20.2. Currently, the FDA is considering greater flexibility in the use of health claims on foods, but other

TABLE 20.2 Examples of Approved Model Health Claims Used on Food Labels

- Calcium and lower risk of osteoporosis
- Sodium and a greater risk of hypertension (high blood pressure)
- Saturated fat and cholesterol and a greater risk of coronary heart disease (CHD)
- Dietary fat and a greater risk of cancer
- Fiber-containing grain products, fruits, and vegetables and a reduced risk of cancer
- Fruits, vegetables, and grain products that contain fiber (particularly soluble fiber) and a reduced risk of CHD
- Fruits and vegetables and a reduced risk of cancer
- Folate and reduced risk of neural tube defect
- Sugar alcohols and reduced risk of tooth decay
- Soluble fiber from whole oats and psyllium seed husk and reduced risk of CHD
- Soy protein and reduced risk of CHD
- Whole grains and reduced risk of CHD and certain cancers
- Plant sterol and plant stanol esters and reduced risk of CHD
- Potassium and reduced risk of high blood pressure and stroke

claims outside of these may not be used on food products. Health claims for dietary supplements is being constructed (www.cfsan.fda.gov).

ALLERGENS

Food product legislation for more simple wording and common sense labeling is supported by the Food Allergy Initiative (FAI), the Food Allergy and Anaphylaxis Network, and the Center for Science in the Public Interest (CSPI). It has been suggested that perhaps labels should just say "wheat" or say "milk products." This is in part due to food allergies. Additional information on food allergens is found in the chapter on food safety (Chapter 16).

Food Allergen Labeling and Consumer Protection Act of 2004

SEC. 201. Short Title
SEC. 202. Findings
SEC. 203. Food Labeling; Requirement of Information Regarding Allergenic Substances—Effective 1/1/06
SEC. 204. Report on Food Allergens
SEC. 205. Inspections Relating to Food Allergens
SEC. 206. Gluten Labeling
SEC. 207. Improvement and Publication of Data on Food-Related Allergic Responses
SEC. 208. Food Allergies Research
SEC. 209. Food Allergens in the Food Code
SEC. 210. Recommendations Regarding Responding to Food-Related Allergic Responses
http://www.cfsan.fda.gov/~dms/alrgact.html (FDA)

Allergen food labeling is required after or adjacent to the ingredients list if a food may/does contain allergens. The Food Allergen Labeling and Consumer Protection Act of 2004 (FALCPA) requires that food manufacturers identify foods that contain the presence of protein derived from crustacean shellfish, eggs, fish, milk, peanuts, soybeans, tree nuts, or wheat. Use of any ingredients that may contain protein from these eight major allergens must be clearly stated for the consumer (see Chapter 16 for Safety).

LABELING FOR FOOD SERVICE

The inclusion of material in this food service labeling section is intended to clarify labeling requirements of food served for immediate consumption. While this section addresses the *menu*, and *not labels* on packaged foods, it may be of less concern to the food scientist. Yet, foods eaten at a food service operation represent a significant portion of the buying public's consumption, and therefore deserve attention.

The FDA encourages food service operations to provide nutrition and health claims to consumers, and further regulations may be forthcoming. Yet, nutrition analysis testing and Nutrition Facts labeling are *not* required of food service (8).

Any nutrient content or health claims appearing on menus must be substantiated by the food service operation, either verbally or in written form, to consumers who request such information. Claims must meet established FDA criteria specified in the CFR; a reliable cookbook or computer software program may be used as a reference, and preparation methods must support the claim or the menu item must be removed from the menu.

The Code of Federal Regulations (21CFR101) specifies the following with regard to labeling for food service: "A nutrient claim used on food that is served in restaurants or other establishments in which food is served for immediate human consumption or which is sold for sale or use in such establishments shall comply with the (same) requirements of this section . . . except that . . .

"In lieu of analytical testing, compliance may be determined using a reasonable basis for concluding that the food bears the claim meets the definition for the claim. This reasonable basis may derive from recognized data bases for raw and processed food, recipes, and other means to compute nutrient levels in the foods or meals and may be used provided reasonable steps are taken to ensure that the method of preparation adheres to the factors on which the reasonable basis was determined (eg, types and amounts of ingredients, cooking temperatures, etc). Firms making claims on foods based on this reasonable basis criterion are required to provide to appropriate regulatory officials on request the specific information on which their determination is based and reasonable assurance of operational adherence to the preparation methods or other basis for the claim."

"A term or symbol that may be in some contexts constitute a claim . . . may be used, provided that the use of the term or symbol does not characterize the level of a nutrient, and a statement that clearly explains the basis for the use of the term or symbol is prominently displayed and does not characterize the level of the nutrient. For example, the term such as "lite fare" followed by an asterisk referring to a note that makes it clear that in this restaurant, "lite fare" means smaller portion sizes than normal; or an item bearing a symbol referring to a note that makes clear that this item meets the criteria for the dietary guidance established by a recognized dietary authority would not be considered a nutrient content."

"Such claim is exempt from the requirements for disclosure statements . . ."

According to a 1994 survey of the Research and Development Directors of 150 of the 400 largest food service corporations (9, 10), "most companies were neutral about their willingness to use nutrition labeling." There were menu-related obstacles to nutrition labeling, such as menu variations, including use of daily specials, limited page space, and loss of flexibility. There also were personnel-related obstacles, such as difficulty in training employees and a shortage of time.

Today there are information options. Nutrition expertise (11) and labeling assistance could be provided to companies by dietitians, as 20% of the largest restaurant chains "employed a *registered dietitian* who could assist with the development of health-related menu offerings"(12). Nutrition and labeling in food service is further discussed in other sources (13–16).

The National Center for Nutrition and Dietetics of the American Dietetic Association has a *hot-line number* (800-366-1655) that offers messages and personally answers consumer questions about food labeling (17).

Supermarket Savvy Information and Resource Service® is an example of a *service* that provides new product information. A newsletter is included as one part of its service. It is written for the health professional and designed to provide information about new products (especially the healthier ones) so that the health professional can answer his/her clients' questions about new foods and guide his/her clients to better food choices in the supermarket and health/natural foods store (18).

CONCLUSION

Concluding this issue is difficult to do. This chapter cannot close. However, suffice it to say that government regulation, industrial compliance, and consumer education are all means of ensuring a safe food supply to consumers. The FDA is a public health agency that regulates food, cosmetics, medicines, medical devices, and radiation-emitting products, such as microwave ovens. The Food, Drug and Cosmetic Act of 1938 and its amendments were introduced to regulate the processing of many products subject to interstate commerce or import. Food inspections are the responsibility of the FDA, with meat product inspection regulated by the USDA. Food packaging and labeling is regulated by the FDA and USDA for their respective products. The USDA administers the Food Safety and Inspection Service and numerous food programs.

The NLEA is an attempt to protect the consumer against fraud and misinformation. Labeling terms, "Nutrition Facts," and health claims are regulated by the FDA. The purpose of the NLEA is to assist consumers in selecting foods that can lead to a healthier diet, eliminate confusion, and encourage production innovation by the food industry. With greater knowledge of nutrients nutrient interactions and promotion of health, greater health benefits may be provided with the formulation of new food products.

GLOSSARY

Daily value (%DV): Two sets of values used on nutrition labels, including Reference Daily Intakes (RDI), based on former US RDAs and Daily Reference Values (DRV) of nutrients that do not have an RDA but have a significant health impact.

Generally Recognized as Safe (GRAS): Substances (food ingredients) generally recognized as safe for their intended use.

Grading service: Conducted as a voluntary service of the USDA, paid for by packers.

Health claims: Describe an association between a nutrient or food substance and disease or health-related condition.

Inspection service: Of the USDA or state Department of Agriculture inspects and stamps inspected meat with a circle containing the abbreviations for "inspected and passed."

Nutrition labeling: For the purpose of assisting consumers in selecting foods that can lead to a healthier diet, to eliminate consumer confusion, and to encourage production innovation by the food industry. Labeling expresses nutrients in terms of Reference Daily Intakes (RDI) and Daily Reference Values (DRV), both comprising the Daily Values.

Standard of Fill of Container: FDA standard that the volume of packaged food offered for sale does not interfere with the weight of the product as stated on the label.

Standard of Identity: FDA list of required and optional ingredients that are included in manufacture.

Standards of Minimum Quality: FDA minimum quality standards for specific food characteristics—color, etc.

Wholesome: The carcass and viscera of the animal were examined and no signs of illness were indicated, and conditions met sanitary standards.

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APPENDICES

INTRODUCTION

I. Considering the frequency with which terms are used (and used interchangeably!) on labels and in the press, a brief discussion and explanation of terms are provided in the appendices that follow:

Appendix A. Biotechnology and Genetically Modified Organisms (GMOs)

Appendix B. Functional Foods

Appendix C. Nutraceuticals

Appendix D. Phytochemicals

Appendix E. Medical Foods

II. In food companies the food scientist who develops new products, the technical staff, and the marketer of these foods must stay abreast of the health concerns of consumers who are making dietary changes in managing their personal health care. An expertise in foods, culinary knowledge, consumer food acceptability, food engineering, food laws, ingredient technology, nutrition, and more position the food company for product success (see Appendix H).

Appendix F. USDA Food Pyramid

Appendix G. Food Label Heath Claims

Appendix H. Research Chefs Association Certification as a Culinary Scientist and More

III. New on the horizon:

Appendix I. Human Nutrigenomics

All of these hold great significance for the food scientist today and in the future. Before we forget though, despite what foods *should* and *could* do—taste still rules! A food must please the palate to remain on the shopping list.

APPENDIX A

Biotechnology

Modern methods of ***biotechnology*** or *genetic engineering* have led to the production of specific desired traits in plant material. There exists breeding of new types of produce, disease-resistant strains, and longer shelf life. Much of biotechnology addresses *crops*, such as corn, soy, cotton, canola, pepper and squash, however, biotechnology is not limited to fruits and vegetables. For example, according to the International Food Information Council (IFIC) rennet, an enzyme for making cheeses and yeast for breads are commonly produced by biotechnology. Beyond these applications, biotechnology produces specific desired traits in animals and microorganisms too.

Modern genetic engineering, in practice since the 1970s, is a biotechnology development that inserts a desired gene into another crop's chromosomes. The resultant cells may be grown into plants, and then conventional breeding techniques follow to yield crops with specific desirable traits. The entire crop is *not* representative of clones of one original plant; the individual plants of a crop are *unique*. For example, prior to biotechnology, rennet was obtained from the intestinal tract of calves' stomach. Now, the specific gene is available because it may be removed and reproduced in bacteria.

According to the USDA's Animal and Plant Health Inspection Service (APHIS), companies or organizations that wish to field-test a genetically engineered crop must obtain permission from the USDA. *Low-risk* traits for familiar crops may have streamlined approval through a *notification procedure*, while *high-risk* traits used for producing pharmaceuticals or industrial compounds require a *permit*. Regardless, field sites are inspected and records audited by APHIS officers.

Biotechnology Regulatory Services (BRS) protects and promotes US agricultural health by ensuring the safe development and use of agricultural biotechnology products. In June 2002, APHIS created the BRS "to place increased emphasis on our regulatory responsibilities for biotechnology. However, while BRS was established fairly recently, APHIS has a long history of regulating agricultural biotechnology products, overseeing the safe conduct of more than 10,000 field tests of genetically engineered crops and the deregulation, or removal from government oversight, of more than 60 products.

. . . While biotechnology holds enormous potential for reducing herbicide use, increasing crop health and production, and manufacturing medicines and industrial products, the challenges posed by biotechnology highlight the importance of the regulation of this technology. APHIS BRS is committed to ensuring a dynamic, robust regulatory system based on science and risk which ensures safe field testing and product development in the US, and is mindful of the global implications of our work" (APHIS) www.aphis.usda.gov/.

As mentioned, field sites are inspected and records audited by APHIS officers. Some infractions, investigation, and deliberation result in civil fines and compensation for damage or remediation. Biotechnology should *improve, not harm* the environment or its people. Currently there is strict legislation for use and safety;

however, according to some environmentalists, this may not have appeared to be the case with initial genetic engineering a decade ago.

For additional information see:
www.ific.org/food/biotechnology/index.cfm

Genetically Modified Organisms (GMOs)

To date, many genetically modified organisms (GMOs) have been approved and seeds have received approval for planting. For example, genetically modified seeds for crops including soy, maize, and cotton are *routinely* planted in the United States. Papaya, potatoes, squash, and tomatoes and more are also produced.

In the United States, GMO's have USDA, FDA, EPA and other independent agency oversight for environmental and food safety protection allowing consumers to be confident and accept usage of GMO's. However, this acceptance is not universal. Many European consumers for example, do not have independent regulatory agencies which function independently from the industry that they regulate. This poses a dilemma for acceptance of GMO's by the consumer. Ultimately, it is the consumer's decision, however, the food industry is responsible for promoting safe and environmentally sound practices in utilizing GMOs.

The *initial* wave of GMO concentrated on insect resistance and herbicide tolerance. The *next* wave, already seen in the US, includes developing select attributes—fat type and so forth. The yield is functional or designer foods. In the *future*, entire manufacturing facilities may be dedicated to the production of genetic materials for medical, pharmaceutical and foods use. (eg, IdentiGEN Genetic Testing Services).

APPENDIX B

Functional Foods

Hopefully all foods are “functional” in that they provide aroma, taste, nutritive value, and perhaps “comfort.” Yet, the term “functional food” carries a different connotation: that those named foods provide benefit *beyond* that of basic nutrition. Foods may be modified by the addition of nutrients not inherent to the original counterpart [1]. Wise food choices may increase control of personal health.

Functional foods are a newly evolving area of food and food technology (Chapter 20), which are defined as:

> “Any modified food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains” (2,3).

The term *functional foods* has *no* legal or general acceptance in the United States. However, it is defined by the Institute of Medicine’s Food and Nutrition Board (IOM/ FNB) and is accepted by some as a modified food or food ingredient for specified health use (4–6). The International Food Information Council (IFIC) defines it as “. . . foods or dietary components . . .” ;“foods that provide health benefits beyond basic nutrition” (7). (So, it may be seen that “beyond” is the operative word!)

According to the IFIC report in “Functional Foods” the *simplest* functional foods are *unmodified* foods such as fruits and vegetables (that Americans do not eat enough of by the way!) (Chapter 7) Examples include broccoli, garlic, oats, purple grapes, soy food, tea, and tomatoes. For example, tomatoes are rich in the food ingredient lycopene and carrots are rich in beta carotene. Other functional foods may be *modified* foods including *fortified* foods and foods *enriched* with components such as phytochemicals. Thus these foods are supportive of health beyond basic nutrition.

The idea of functional foods originated in Japan in the mid 1980s. Foods processed to contain specific ingredients significant to health and disease prevention were studied. The aim was to solve medical problems such as high blood pressure. Today *in Japan* products must meet eligibility requirements of the Japanese Ministry of Health and Welfare to bear the approval stamp FOSHU—Foods for Specified Health Use. Today, *in the U.S.*, the functional food category is *not* recognized legally; however, many foods are created to target diseases such as cancer, diabetes, heart disease, hypertension and more.

They have been associated with the treatment and/or prevention of other medical maladies including neural tube defect and osteoporosis, as well as abnormal bowel function and arthritis [8].

While research shows beneficial properties of specific substances, such as iron and vitamins, their *survival* in the food manufacturing process and their *contribution* to appearance, texture, and flavor are also important considerations. Usage of functional food components by an individual and/or company must consider the risk:benefit ratio and follow acceptable scientific guidelines with regard to toxicity [9]. With availability of these types of foods, greater health benefits may be provided by the formulation of food products with added nutrients/nutrient combinations (10).

Further reference material may be found in the following website sources:
Ex. 1 - www.eatright.org search functional foods

Margarine, psyllium, soy, whole wheat, cranberry juice, fatty fish, garlic, vegetables—artichoke, onion powder, ripe banana; green tea, black tea, spinach, tomatoes, meats—lamb, turkey, beef; cruciferous vegetables, fermented dairy products, tree nuts, grape juice, and red wine are discussed.

“Functional foods are foods that have health benefits beyond the nutrients they contain . . . In most foods, functional benefits probably come from several, perhaps many, food substances . . . Many fruits, vegetables and grain products have plant substances that may help reduce the risk for certain health diseases such as heart disease and some cancers.

Although more research is needed to learn about the full potential of functional foods, it is clear that functional foods play a role in good health when combined with balanced food choices and physical activity.”

Ex. 2 - http://www.nutriwatch.org/04Foods/ff.html

This site has excellent material.

Functional foods from *plant sources* are listed below. Select references are also included following each functional food named:

- **Citrus fruits.** Cancer protection.
- **Cranberry.** Treatment of urinary tract infections, as it causes acidification of the urine.
- **Cruciferous vegetables.** Cancer risk.
- **Flaxseed.** Reduce total and LDL cholesterol.
- **Garlic.** Cancer risk.
- **Oats.** Cholesterol, coronary heart disease.
- **Soy.** Cancer, cardiovascular disease (CVD), osteoporosis, and lessening negative menopausal symptoms.
- **Tea.** Inconclusive results from epidemiological studies. (The FDA stance on green tea is that it does not reduce breast, prostate or any other type of cancer. Further research is ongoing.)
- **Tomatoes.** Lycopene as the primary carotenoid may benefit for some cancers, myocardial infarction.
- **Wine and grapes.** May reduce the risk of cardiovascular disease.

Functional foods from *animal sources* are listed in the website also.

There are a number of animal products that contain various physiologically-active components, and thus play a potential role in health. Animal sources: fish, dairy, beef.

Ex. 3 - www.ific.org/publications/factsheets/preprobioticsfs.cfm

Examples of Probiotics and Prebiotics

Certain species and strains of *Lactobacilli*, *Bifidobacteria*, Yeast

Certain yogurts, other cultured dairy products, and non-dairy applications May improve gastrointestinal health and systemic immunity

Prebiotics Inulin, Fructo-oligosaccharides (FOS), Polydextrose, Arabinogalactan, Polyols-lactulose, lactitol

Whole grains, onions, bananas, garlic, honey, leeks, artichokes, fortified foods and beverages, dietary supplements and other food applications May improve gastrointestinal health; may improve calcium absorption

Ex. 4 - www.ific.org/nutrition/functional/index.cfm

The Scientific Status Summary of the Institute of Food Technologists reviewed the literature for the primary plant and animal foods linked with healthful benefits. The review focused on foods rather than specific compounds isolated from foods (11).

“Although the term “functional foods” may not be the ideal descriptor for this emerging food category, focus-group research conducted by the IFIC showed that this term was recognized more readily and was also preferred by consumers over other commonly used terms such as ’nutraceutical’ or ’designer foods.’ Widespread use and general acceptance of the term ’functional foods’ by the media, scientists, and consumers have led the ADA to work within this framework rather than introduce a new, more descriptive term.”

“It is the position of the American Dietetic Association (ADA) that specific substances in foods (eg, phytochemicals and naturally occurring components and functional food components) may have a beneficial role in health as part of a varied diet. The Association supports research regarding the health benefits and risks of these substances. Dietetics professionals will continue to work with the food industry and government to ensure that the public has accurate scientific information in this emerging field” (ADA).

Of more recent note is the FDA regulatory debate on the definition of functional foods. A defined category and new labeling requirements may be on the horizon for such foods. Several parties identified in the following, have contributed to input in public hearings.

- The Food Products Association (FPA)
  - Stance: No separate category or definition is required for functional foods
  - “Current statutory and regulatory provisions require that ingredients used in the formation of any food, including those that bear health , or structure-function claims, must be approved food additives, or generally recognized as safe (GRAS), for the intended use." (FPA) "This would include any novel or unique ingredients being incorporated into foods for functional benefits” (FPA)
- The Institute of Food Technologists (IFT)

  - Advocate of functional food category for several years. A new category is needed so that food marketers could describe items as functional foods, as long as labels were reflective of scientific evidence.
  - “Under existing regulatory policies, some food label claims cannot be factual and still accurately represent the science. This limits the scope and accuracy of consumer information and hinders the development and marketing of functional foods.” (IFT)

- The Center for Science in the Public Interest (CSPI).
  - Wary of the creation of a new category. In theory it may help consumers. In *practice*, industry and government regulators may not make it workable.
  - “The food industry is pressuring the … Administration to extend already weak standards for … ingredients and label claims … about as dependable as 19th -century snake oil.”

APPENDIX C

Nutraceuticals

Nutraceuticals is the name given to a proposed new regulatory category of food components that may be considered a food or part of a food. Although they may supply medical or health benefits including the treatment or prevention of disease, the FDA does *not* recognize the term. These are often referred to as 'phytochemicals' or 'functional foods'.

The term ***nutraceutical*** (Chapters 7, 18, 20) is *not* recognized by the Food and Drug Administration (FDA) and is outside FDA regulations because of the following:

Foods are defined as "products primarily consumed for their taste, aroma, or nutritive value."

Drugs are defined as "intended for use in the diagnosis, cure, mitigation, treatment or prevention of disease or to affect the structure or a function of the body" [11].

Again, as for the Food and Drug Administration stance, substances that influence our health are either a *food* or a *drug*. The category of food is further divided into *conventional food* and *dietary supplements*. Unlike prescription drugs or over-the-counter medicines, dosages and composition of some nutraceuticals do *not* need to meet a quality control standard. Of course, this leads to skepticism and may be harmful to users who believe and follow claims made by the manufacturer of nutraceuticals.

Nutraceuticals are defined by the Foundation For Innovation in Medicine as:

> "Any substance that may be considered a food or part of a food and provides medical or health benefits, including the prevention or treatment of disease. Nutraceuticals may range from isolated nutrients, dietary supplements, and diets to genetically engineered "designer" foods, herbal products, and processed products, such as cereals, soups, and beverages" [12].

According to the *American Nutraceutical Association*, nutraceuticals are functional foods with properties which are potentially disease-preventing and health promoting. They also include naturally occurring dietary substances in forms similar to pharmaceutical dosages—capsules, etc.—and "dietary supplements" as defined by the Dietary Supplement Health and Education Act of 1994 (DSHEA).

The Nutraceuticals Institute is a joint partnership of Rutgers (State University of New Jersey) and St. Joseph's Philadelphia Jesuit University. Nutraceuticals are defined as "natural, bioactive chemical compounds that have health promoting, disease preventing or medicinal properties". Their mission is to involve universities, government and industry in research, development of safe products and link with the health care industry, and develop markets.

Foods also may be known as *designer foods* or even as referred to as *functional foods*. However, in the case of the latter, according to the American Dietetic Association, functional foods are products whose nutritional value is enhanced by natural ingredient addition, and they may offer health benefits when consumed as part of a varied diet (ADA).

APPENDIX D

Phytochemicals

Phytochemicals (phyto = plant) are important nonnutrients in food that may be responsible for disease prevention such as reduction of cancer. While many frequently consumed foods including grains, legumes, seeds, fruits, and vegetables as well as green tea *naturally* are a source of phytochemicals, a product may contains *added* phytochemicals (Chapters 7 and 18). If added, the label must state on the food package that the product contains phytochemicals; however, no nutritional claim may be made other than stating the already approved (Table 20.2) nutritional or medical benefits that are based on sound scientific data.

Therefore, whether naturally available in the diet, added or in supplement form, phytochemicals are defined as:

> “Substances found in edible fruits and vegetables that may be ingested by humans daily in gram quantities and that exhibit a potential for modulating human metabolism in a manner favorable for cancer prevention” [2].

Examples: The list is long of the many examples of such plant chemicals. It includes the following:

- Carotenoids: beta-carotene, orange and yellow pigmented, and green leafy vegetables
- Flavonoid group of pigments: many fruits and vegetables
- Indoles, isothiocyanates: cruciferous (“cross-shaped blossom,” cabbage family) vegetables
- Isoflavones: soybeans, tofu
- Limonoids: citrus
- Lycopene: tomatoes
- Phenols: many fruits and vegetables
- Polyphenols: grapes, green tea, red wine
- Protease inhibitors: beans
- Saponins: legumes (beans and peas)
- Sterols: broccoli, cabbage, cucumbers, egg plant, peppers, soy, whole grains
- Sulfur-containing allyl sulfide and sulforaphane: garlic, leeks, onion
- Terpenes: cherries, citrus peel

These are among the plant chemicals that may be effective in disease prevention. http://lpi.oregonstate.edu/infocenter/phytochemicals/flavonoids/#disease_prevention

APPENDIX E

Medical Foods

Medical foods are regulated by the FDA Office of Special Nutritionals on a case-by-case basis. They are used as enteral foods (not administered into a vein parenterally, but not traditional foods) to improve nutritional support of the hospitalized patient. In 1988, Congress provided the first legal definition of "medical food" as food formulated to be consumed or administered enterally under the supervision of a physician and which is intended for the specific dietary management of a disease or condition for which distinctive nutritional requirements based on recognized scientific principles are established by medical evaluation (US Congress, 1988).

Medical foods either may supplement the diet or may be the sole source of nutrition and they are used based on medical evaluation. Currently, such medical foods may not be subject to NLEA labeling regulations, as they are not considered the same as foods for special dietary use. The fact that both categories of foods often overlap poses new FDA policy/regulatory discussion. The USDA recognizes medical foods as nonprescription nutrition used for dietary management of a disease or condition. Such foods the same as reduced-fat or low-sodium. They are not used by the general public and are not available in super markets.

Hippocrates suggested: "Let food be thy medicine and medicine be thy food."

For more information, please see:
http://www.cfsan.fda.gov/~lrd/fr961129.html

APPENDIX F

MyPyramid.gov

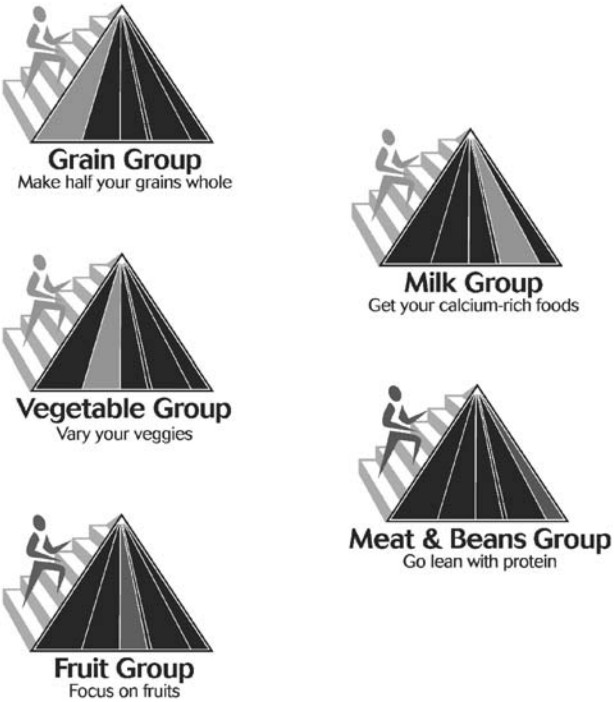
American Dietetic Association - Nutrition Care Manual
http://www.nal.usda.gov/fnic - Search: International Food Guide

- go to Comparison of international food guide pictorial representations
- view appropriate age and cultures - Mexican, Asian, etc.

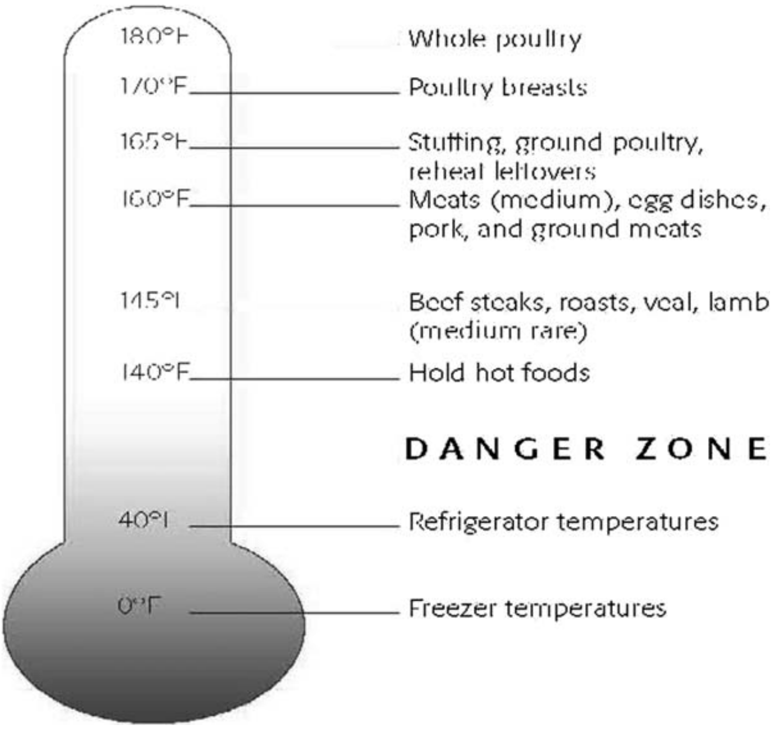
USDA Pyramid. A number of countries have developed/revised their own food guide illustrations. They "have different food availabilities, food preferences, dietary patterns, and cultural definitions of foods." Universal dietary recommendations do not exist. Examples are Australia, Canada, China, Germany, Great Britain, Korea, Mexico, Philippines, Portugal, Puerto Rico, Sweden, US [14].

Play It Safe with Food (USDA MyPyramid.gov). Know how to prepare, handle, and store food safely to keep you and your family safe:

- Clean hands, food-contact surfaces, fruits, and vegetables. To avoid spreading bacteria to other foods, meat and poultry should *not* be washed or rinsed.
- Separate raw, cooked, and ready-to-eat foods while shopping, preparing, or storing.
- Cook meat, poultry, and fish to safe internal temperatures to kill microorganisms.
- Chill perishable foods promptly and thaw foods properly.



(*Source*: USDA – MyPyramid.gov).



APPENDIX G

Food Label Health Claims

Health claims describe an association between a nutrient or food substance and disease or health-related condition. Food processors may choose to use any additive, including nutrients or nonnutrient supplements, in the manufacture of food products. Regardless of what is used, they must comply with all Nutrition Labeling and Education Act (NLEA) regulations regarding the contents and stated **health claims** of their products. They must use vitamin and mineral additives judiciously (not just to enhance the values on their food label), and then only make label claims regarding nutritional benefits that are allowed (Chapter 20). A research dietitian with the USDA Agricultural Research Services has said:

> "Open, academic research, including human testing of isolated food components (eg, vitamins, minerals, amino acids, fatty acids, sugars, dietary fibers, and many other food components) has been fundamental to the development of nutrition science. Federal regulations (through FDA) and funding should be encouraged to promote human research and clinical testing of the health benefits of foods and food components, consistent with good science, safety, and the Nutrition Labeling and Education Act of 1990.
>
> Although compounds in foods that must be concentrated to obtain physiologic effects should be regulated as drugs, foods and purified food constituents in amounts commonly consumed should not be classified as drugs simply because they are being tested for potential health effects or disease prevention. Research should not be discouraged by requiring investigative new drug procedures for substances in amounts available in the diet" (11).

Examples of approved health claims:

- Calcium and lower risk of osteoporosis
- Sodium and a greater risk of hypertension (high blood pressure)
- Saturated fat and cholesterol and a greater risk of coronary heart disease (CHD)
- Dietary fat and a greater risk of cancer
- Fiber-containing grain products, fruits, and vegetables and a reduced risk of cancer
- Fruits, vegetables, and grain products that contain fiber (particularly soluble fiber) and a reduced risk of CHD
- Fruits and vegetables and a reduced risk of cancer
- Folate and reduced risk of neural tube defect
- Sugar alcohols and reduced risk of tooth decay
- Soluble fiber from whole oats and psyllium seed husk and reduced risk of CHD
- Soy protein and reduced risk of CHD
- Whole grains and reduced risk of CHD and certain cancers
- Plant sterol and plant stanol esters and reduced risk of CHD
- Potassium and reduced risk of high blood pressure and stroke
  http://vm.cfsan.fda.gov/label.html

The FDA allows health claims to be one of three types:

- Unqualified health claims (allowed since 1993) The claim must meet the Significant Scientific Agreement (SSA) standard
- Qualified health claim (2003). SSA not met. Use of the term "may".

Structure/function claims. The effect that a substance has on the structure or function of the body – not a specific disease. i.e. Calcium and strong bones

Information for health claims is found at:
http://www.cfsan.fda.gov/~dms/lab-ssa.html

http://a257.g.akamaitech.net/7/257/2422/01jan20061800/edocket.access.gpo.gov/2006/06-4703.htm

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APPENDIX H

Research Chefs Certification as a Culinary Scientist and More

The Research Chef's Association (RCA) certifies that food science, as well as culinary knowledge is held by an individual (www.researchchef.org or http://www.culinology.com).

The Research Chefs Association Certification Commission (RCACC) was founded in 2003. It was to "promulgate policies, procedures and criteria which will enhance the certification process for Certified Research Chefs (CRCs) and Certified Culinary Scientists (CCSs). To guide its activities, the RCACC strives to meet National Commission for Certifying Agencies (NCCA) standards" (RCA).

According to the RCA, it is "the leading professional community for food research and development. Its members are the pioneers of the discipline of Culinology®, or the blending of culinary arts and the science of food." More than 2,000 chefs, food scientists, and other industry professionals are working on the future of research and development.

Certified Research Chef Eligibility (CRC). "In order to be eligible to become a Certified Research Chef, applicants first must meet eligibility criteria in the categories of Education, Food Service Experience, and Research and Development Experience. Having done so, candidates then must pass a certification exam on their knowledge of food science and related subjects" (RCA).

Certified Culinary Scientist Eligibility (CCS). "In order to be eligible to become a Certified Culinary Scientist, applicants must first meet eligibility criteria in the categories of Education, Food Science Experience, and Food Service Experience. Having done so, candidates then must pass a certification exam on their knowledge of culinary arts and related subjects" (RCA).

RCACC Approved Definitions for Eligibility. "A *Research Chef* for purposes of certification is defined as one who works in food product development, has expertise in culinary arts, and a baseline knowledge of food science.

A *Culinary Scientist* for purposes of certification is defined as one who works in food product development, has expertise in food science/technology, and a baseline knowledge of culinary arts. *Food Science Related Degrees* include Culinology®, Food Technology, Microbiology, Chemistry, Nutrition, Biochemistry, Meat Science, Dairy Science, Cereal Science, Biology, Fish Science, Poultry Science, and Food Engineering" (RCA).

APPENDIX I

Human Nutrigenomics

By definition *genomics* refers to the *complete* genetic makeup of an organism. Some human genomic test assessments began in the 1980s and only now are becoming more available. Results may show a patient's individual risk of disease or its recurrence, which can help medical care providers and patients make better informed and more personalized treatment decisions.

Nutrigenomics is the new science of *nutritional genomics*. It is the application of the science of genomics to human nutrition and it views the relationship between nutrition and health. Research in nutrigenomics covers *cellular and molecular processes* and the relation to many diseases, including degenerative diseases such as atherosclerosis and cancers, as well as aging. Research is focused on the *prevention* of disease and requires understanding of nutrient-related interactions at the level of the gene.

Nutrigenomics can be approached in more than one way. For instance, personalized nutrition may be offered to people based on small differences in their genome (single nucleotide polymorphisms, or SNPs) compared to another person. Nutrigenomics also can be considered when molecules in certain foods have the ability to change the expression of genes in an individual, by increasing or decreasing the expression of a gene into a protein. An example of each of these is given below.

Personalized nutrition may be used as evidence accumulates that certain foods may be harmless to some people but detrimental to others. For instance, some people have a version of a gene that codes for a protein that makes them susceptible to myocardial infarction (MI) with intake of caffeine because they metabolize caffeine slowly, while others with a different version of the same gene make a protein that metabolizes caffeine quickly and their risk for MI is lowered. People with the slow version gene could be counseled about their increased risk for MI with caffeine intake [15].

Food also comes into play when considering gene expression in general. Not all genes are expressed in all tissue; only those genes necessary for that tissue are expressed into proteins. Researchers are finding that certain molecules in foods can affect the expression of certain genes. For instance, research has shown that vitamin D can increase the expression of genes that code for anti-inflammatory proteins and decrease the expression genes coding for pro-inflammatory proteins, thus helping with chronic inflammatory conditions such as autoimmune disease. Vitamin D is a fat soluble and should not be taken in excess [16].

(This Nutrigenomics Appendix I is written with the assistance of B.L. Mark PhD, RD, the University of Texas Southwestern Medical Center, at Dallas, the Department of Clinical Nutrition.)

GLOSSARY

Biotechnology. Biogenetic engineering of animals, microorganisms, and plants to alter or create products that have increased resistance to pests, improved nutritive value, and shelf life.

Culinary Scientist. For certification defined as one who works in food product development, has expertise in food science/technology, and baseline knowledge of culinary arts.

Drugs. Intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease to affect the structure or function of the body.

Enrichment. The addition of nutrients to achieve established concentrations specified by the standards of identity.

Foods. Products primarily consumed for their taste, aroma, or nutritive value.

Fortification. The addition of nutrients at levels higher than those found in the original or comparable food.

Functional Foods. Any modified food or food ingredient that may provide a health benefit beyond that obtained by the original food; the term has no legal or general acceptance in the United States but is accepted by some as food for specified health use.

Genetically Modified Organisms (GMOs). Genetically modified seeds for crops.

Medical Foods. Food formulated to be consumed or administered enterally under the supervision of a physician and which is intended for the specific dietary management of a disease or condition for which distinctive nutritional requirements based on recognized scientific principles are established by medical evaluation (US Congress 1988).

Nutraceuticals. The name given to a proposed new regulatory category of food components that may be considered a food or part of a food and may supply medical or health benefits including the treatment or prevention of disease; a term not recognized by the FDA.

Nutrigenomics. The new science of *nutritional genomics*. It is the application of the science of genomics to human nutrition.

Phytochemicals. Plant chemicals; natural compounds other than nutrients in fresh plant material that function in disease prevention; they protect against oxidative cell damage or facilitate carcinogen excretion from the body and exhibit a potential for reducing the risk of cancer.

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