Active and Intelligent Packaging: Innovations for the Future

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Introduction

Food packaging exists to make our lives easier. We need packaging to contain foods, protect foods from the outside environment, for convenience, and to communicate information to consumers about the food inside the package. Containment is the most basic function of a package. Even fresh produce, which is displayed unpackaged at the store, must be transported out of the store in some type of container. Packaging provides protection of food from adulteration by water, gases, microorganisms, dust, and punctures, to name a few. A food package communicates important information about the product, how to prepare it, and information about the nutritional content. Packaging also allows for consumers to enjoy food the way they want, at their convenience. Food packages can be geared toward a persons own lifestyle through designs like portability and single serving dishes. Although traditional packaging covers the basic needs of food containment, advances in food packaging are both anticipated and expected. Society is becoming increasingly complex and innovative packaging is the result of consumers' demand for packaging that is more advanced and creative than what is currently offered. Active packaging and intelligent packaging are the result of innovating thinking in packaging.

Defining Active Packaging and Intelligent Packaging

To understand what active and intelligent packaging have to offer the world of packaging, it is important to clarify what each phrase means. Active packaging is accurately defined as “packaging in which subsidiary constituents have been deliberately included in or on either the packaging material or the package headspace to enhance the performance of the package system” (Robertson, 2006). This phrase emphasizes the importance of deliberately including a substance with the intention of enhancing the food product. Active packaging is an extension of the protection function of a package and is commonly used to protect against oxygen and moisture.

Intelligent packaging can be defined as "packaging that contains an external or internal indicator to provide information about aspects of the history of the package and/or the quality of the food" (Robertson, 2006). Intelligent packaging is an extension of the communication function of traditional packaging, and communicates information to the consumer based on its ability to sense, detect, or record external or internal changes in the product's environment.

Active Packaging: Packaging Gets Active

Active packaging systems are developed with the goal of extending shelf life for foods and increasing the period of time that the food is high quality. Active packaging technologies include some physical, chemical, or biological action which changes interactions between a package, product, and/or headspace of the package in order to get a desired outcome (Yam et al., 2005). The most common active systems scavenge oxygen from the package or the product and may even be activated by an outside source such as UV light (Gander, 2007). Active packaging is typically found in two types of systems; sachets and pads which are placed inside of packages, and active ingredients that are incorporated directly into packaging materials.

Active Packaging: Sachets and Pads

In order to absorb or emit gases to a package or headspace, sachets and pads are very commonly used. Sachets were developed in the late 1970s in Japan. For oxygen scavenging, the sachets essentially utilize the process of rusting, or the oxidation of iron compounds in the presence of oxygen and water. Oxygen scavengers can also be made based on enzyme technology. Oxygen absorbers are usually made of powdered iron or ascorbic acid. Iron based scavengers typically do not pass the metal detector inspections on most packaging lines, and in these incidences ascorbic acid is advantageous. Oxygen absorbers in sachets are commonly found in meat and poultry products, coffee, pizzas, baked goods and dried foods. Sachets that absorb carbon dioxide along with oxygen are also available and are most commonly found in roasted or ground coffee packages. Some sachets are capable of emitting ethanol as an antimicrobial agent to extend the shelf life of high moisture bakery products. Drip absorbent pads may be used in packages containing meats that are likely to leak after temperature fluctuations. These pads prevent the growth of molds or bacteria by absorbing water into super-absorbent polymer granules placed between two layers of microporous non-woven polymer. Although sachets work well in many applications, they are not appropriate for every situation. Sachets cannot be used in liquid foods. They may not be used in a package made of flexible film, as the film will cling to the sachet and prevent it from performing its function. Sachets have the risk of accidental ingestion by consumers and this may account for their limited commercial success in North America and Europe (Yam et al., 2005).

Active Packaging: Materials Containing Active Components

More recent attempts at active scavenging have focused on incorporating the scavenger into the packaging material itself. This methods has potential for use in polyethylene terephthalate (PETE) bottles and can be included in many plastic containers and closures. Adding scavengers to the plastic rather than a sachet can save many problems. For example, in a packaging film that is tight fitting such as a cheese pack, a sachet to absorb oxygen cannot be used because the tight fitting film would stifle its functionality. Incorporating oxygen absorbing materials into the plastic components of the packaging material could be more efficient. One way in which oxygen absorbers are being incorporated into plastic materials is the use of a polymer based absorber that is coextruded in various packaging structures. The oxygen absorber is activated via UV light so that the scavenging capacity is not exhausted before the end of the product shelf life (Anonymous, 2007). Some systems developed thus far use iron-based chemistry in their packaging material.

Flavor absorbers are also being used in active packaging (Robertson, 2006). It has been known for decades that packaging materials can scalp or absorb flavors from foods such as fruit juices. Scalping is now being used in a positive way to absorb unwanted flavors and odors.

Active Packaging: Anti-microbial Systems for Food Packaging

An exciting innovation in active packaging is the potential for the controlled release of antimicrobials from packaging materials. Antimicrobials incorporated in packaging materials could extend shelf live by preventing bacterial growth and spoilage. In one system, known as “BioSwitch” (de Jong et al., 2005), an antimicrobial is released on command when bacterial growth occurs. The basic concept is that a change in the environment such as pH, temperature, or UV light occurs and the antimicrobial responds accordingly. The external stimulus results in a release of the antimicrobial component of the package. In this system, the antimicrobial is released on command, and the system is active only at specific conditions. This system could potentially increase the stability and specificity of preservation and reduce the amount of chemicals needed in foods. A common example of release on command antimicrobials in food packaging is the inclusion of polysaccharide particles that encapsulate antimicrobial compounds. Many bacteria will digest polysaccharide when they grow, and so if a bacterial contamination occurs, the growth of bacteria will release the antimicrobial compounds and should inhibit subsequent microbial growth.

Intelligent Packaging Systems

Intelligent packaging systems exist to monitor certain aspects of a food product and report information to the consumer. The purpose of the intelligent system could be to improve the quality or value of a product, to provide more convenience, or to provide tamper or theft resistance (Robertson, 2006). Intelligent packaging can report the conditions on the outside of the package, or directly measure the quality of the food product inside the package. In order to measure product quality within the package, there must be direct contact between the food product or headspace and the quality marker. In the end, an intelligent system should help the consumer in the decision making process to extend shelf life, enhance safety, improve quality, provide information, and warn of possible problems. Intelligent packaging is a great tool for monitoring possible abuse that has taken place during the food supply chain. Intelligent packaging may also be able to tell a consumer when a package has been tampered with. There is currently work being developed with labels or seals that are transparent until a package is opened. Once the package is tampered with, the label or seal will undergo a permanent color change and may even spell out "opened" or "stop". Perhaps intelligent packaging will be able to inform a consumer of an event that occurred such as package tampering that may save their life.

Intelligent Packaging: Time-Temperature Indicators (TTIs)

The intelligent packaging design that is leading the way in packaging technology is the time-temperature indicator (TTI). The TTI is useful because it can tell the consumer when foods have been temperature abused. If a food is exposed to a higher temperature recommended, the quality of the food can deteriorate much quicker. A TTI can be placed on shipping containers or individual packages as a small self-adhesive label, and an irreversible change, like a color change, will result when the TTI experiences abusive conditions. TTIs are particularly useful with chilled or frozen foods, where the cold storage during transportation and distribution are important for food quality and safety. TTIs are also used as freshness indicators for estimating the shelf life of perishable products. A TTI technology known as Timestrip is currently being employed by Nestle in their food service products in the UK (Anonymous, 2007). The Timestrip uses a steady diffusion of liquid through a membrane to measure the time that has elapsed at a particular temperature. This action can provide information about how long a product has been opened or in use. The Timestrip is very useful for products like sauces that have to be refrigerated and used within a specific time period.

Intelligent Packaging: Gas Indicators

Food is a complicated material to package because it is capable of respiration and therefore may change its own atmosphere when inside a package. The gas composition within a package can easily change due to the interaction of food with its environment. Gas indicators are a helpful means of monitoring the composition of gases inside a package by producing a change in the color of the indicator though a chemical or enzymatic reaction (de Jong et al., 2005). The indicators must be in direct contact with the gaseous environment directly surrounding the food in a package. Indicators are capable of signaling whether there is a gas leakage in the package, or they may be used to verify the efficiency of an oxygen scavenger. Gas indicators typically signal the presence or absence of oxygen and/or carbon dioxide. Oxygen in the air can cause oxidative rancidity, unwanted color changes in foods, and allow aerobic microbes to grow on foods. Oxygen indicators typically result in a color change when oxygen is present, and the presence of oxygen can indicate that the package has a leak or has been tampered with. Oxygen indicators can also indicate improper sealing of a package. Gas indicators are also being developed to detect water vapor, ethanol, and hydrogen sulfide.

Intelligent Packaging: Thermochromic Inks

Inks are available that are temperature sensitive and can change colors based on temperature. These inks can be printed onto packages or labels such that a message can be conveyed to the consumer based on the color of the ink they are seeing. Thermochromic inks can let a consumer know whether a package is too hot to touch, or cold enough drink. Thermochromic inks are becoming a popular technology for beverages (Robertson, 2006). The inks used can be adversely affected by UV light and temperatures over 121°C, so consumers should not fully rely on the inks message when it comes to deciding the proper time to consume a food.

Active and Intelligent Packaging of the Future

As exciting as the prospect of active and intelligent packaging is, all packaging material must be approved for use, and the legislation that applies to traditional packaging also applies to active and intelligent packaging (Hurme et al., 2002). To date, no specific methods exist to determine whether or not active or intelligent packaging is suitable when in direct contact with foods (Robertson, 2006). A major issue is that most active and intelligent packaging systems require that food be in direct contact with a sensor of some kind, and substances from the sensor may migrate into foods. Whether these migrations are intentional or unintentional, the substance, amount of the substance, and possible health affects of the substance must be determined in order for the substances to be allowed and regulated. In addition, the cost of active and intelligent packaging limits its commercial use. Most active or intelligent systems add cost to the package, so innovations in packaging must have a final beneficial outcome that outweighs the extra expenses of adding the technology. In addition, systems must be reliable and effective. This requires that the system be validated to assure the information being conveyed is true and the consumer is not let down when they trust these news technologies over the old ways. It is also important the the food producer, retailer, and consumer be in tuned with the active or intelligent system on a large scale. Attitudes must be willing to accept new technologies and those involved in each step of the food chain must be sure that the new system is safe and true for the user. Despite these hurdles, many developments are still on their way.

The attitude toward active and intelligent packaging is positive and there is still much potential for exciting innovation to come. The following are some active or intelligent packaging idea that are in the works.

Biosensors for Pathogen or Toxin Identification

Foodborne pathogens are of great concern to the food industry and many consumers have become increasingly aware of this problem. The need to rapidly and accurately detect small amounts of pathogen or toxins in food is an essential step in keeping the consumer safe. A biosensor is an analytical device used to detect a substance, in this case a pathogen, and then transmit this information into some sort of signal that is quantifiable. An intelligent system in the works aims attach antibodies to a plastic packaging surface to detect pathogens or toxins (Yam et al., 2005). If the antibodies come into contact with the target pathogen, the packaging material would display a visual cue to alert the consumer. This intelligent system would only be useful when foods were contaminated with very high concentrations of pathogen or toxin. In reality, a consumer could get ill from just small concentrations of pathogen or toxin and this intelligent system could give the consumer a false sense of security. Also, this system would work only to detect pathogens or toxin on the surface of a food product, and would not alert consumers of the dangerous substances that could potentially be distributed throughout the product. This system has a long way to go before it becomes commercially available.

Microwave Doneness Indicators

Producers of microwave ovenable foods are anxiously anticipating microwave doneness indicators (MDIs). These indicators would be able to detect the readiness of foods that are heating in microwave ovens and signal to consumers when foods are safe to eat. The biggest challenge in this field at the moment is the ability to evenly heat foods in the microwave so that there is a defined stage in which a food could be called safe to eat. Currently, foods heat nonuniformly, and hot spots occur throughout the food. These hot spots would trigger a doneness indicator while cooler regions would not have reached acceptable cooking temperatures. An ideal MDI would be located on the lid or dome of the microwave container so that the consumer could easily see the visual indicator for doneness (Robertson, 2006). This would be functional as a food is heated in the microwave and the space above the food would heat and transfer to the lid. The relationship between the temperature of the food and the temperature of the lid would be the basis of the indicator system. It would be important that the indicator not give false reading because the device itself heats in the microwave. The indicator must also be viewable by the consumer without having to open the microwave. As of yet, MDIs do not exist commercially, but their arrival is much anticipated.

Radio Frequency Identification (RFID)

It is believed that tomorrows food packages will certainly include radio frequency identification (RFID) tags (Gander, 2007). RFID tags are an advanced form of data information carrier that can identify and trace a product. They are currently used for tracking expensive items and livestock (Anonymous, 2007). In a typical system, a reader emits a radio signal to capture data from an RFID tag. The data is then passed to a computer for analysis. RFID tags contain a microchip connected to a tiny antenna. This allows for the tags to be read for a range of 100 feet or more in more expensive tags, to 15 feet in less expensive tags (Yam et al., 2005). The RFID tag could offer much more than a conventional bar-code. In contrast to a bar-code, RFID does not need to be in a direct line-of-sight to be recognized by a scanner. This could revolutionize the way check-out works at a grocery store. Many RFID tags can be read simultaneously at a rapid rate. RFID tags could also store information such as temperature and relative humidity data, nutritional information and cooking instructions. They could be integrated with a time-temperature indicator or a biosensor to carry time-temperature information or microbiological data (Yam et al., 2005). RFID technology in the food system is still in the early stages. Simple applications like tracking and identification are the focus of most food science matters, and these must be perfected before more complex applications can come to light.

The Kitchen of the Future

The use of data processors, scanners, voice recognition, and advances in the internet have innovators in food science and packaging technology thinking big. An idea has been proposed to integrate a convective/microwave oven with a microprocessor, a bar-code scanner and an optional voice recognition device that is connected to a touch screen and the internet (Yam, 2000). The microprocessor would have information about oven characteristics and algorithms. A food item would have a bar code on its package and the information from a bar code could be scanned and passed on to the microprocessor in the oven. The microprocessor would then be able to control magnetron, heating elements and the turntable in the oven to ensure perfect cooking with practically zero interaction from the consumer. If the system works properly, the consumer would be left with a high quality food product without consumer induced problems in cooking. The issue with this system would be that different ovens heat foods differently, different foods have different dielectric and thermal properties, different packages come in different shapes and designs, and cooking from one item to the next will never be perfectly replicated. Although this system is highly technical, it is not an impossibility. There are also several ways in which this system could be altered or simplified based on consumer demand. Although the idea has been planted, this is truly a vision of the future.

Conclusions

Active and intelligent systems are a branch of packaging that is truly innovative and offers exciting opportunities for food safety, quality and convenience. Many active and intelligent packaging concepts are commercially available in the United States. Some experts believe that the next round of technology in packaging will include nanotechnologies that will allow new compounds like novel antimicrobials and gas scavengers to be included in packaging films. The advancement of electronic devices that can be made cheaply will also help drive the innovate direction of active and intelligent packaging. As society continues to advance, the expectations of the consumer will continue to advance. The use of active and intelligent packaging will likely become more popular as more technologies make their way to the market, innovate packaging in active and intelligent systems will become more common place. Perhaps active and intelligent packaging will completely replace traditional packaging itself. And as Paul Gander of Food Manufacture Magazine states, “the trend is towards less packaging, and what there is will be more interactive. Whether 2020 will see packs which literally walk off the shelf is quite another matter”(Gander, 2007).

References:

Anonymous. 2007. Smart packaging: coming to a store near you. Food Engineering & Ingredients. 32:20-23

De Jong, A.R., Boumans, H., Slaghek, T., Van Veen, J., Rijk, R. and Van Zandvoort, M. 2005. Active and intelligent packaging for food: is it the future?. Food Additives & Contaminants: Part A. 22:975-979

Gander, P. 2007. The smart money is on intelligent design. Food Manufacture Feb: xv-xvi

Hurme, E., Sipilainen-Malm, T., and Ahvenainen, R. 2002. Active and intelligent packaging. In *Minimal Processing Technologies in the Food Industry*. Ohlsson, T. and Bengtsson, N. CRC Press, Boca Raton, Fl. Chap. 5

Robertson, G. L. 2006. Active and intelligent packaging. In *Food packaging: principles and practice—2nd ed*. CRC Press, Boca Raton, Fl. Chap. 14.

Yam, K.L. 2000. Intelligent packaging for the future smart kitchen. Packaging Technology and Science. 13:83-85

Yam, K. L., Takhistov, P. T., and Miltz, J. 2005. Intelligent packaging: concepts and applications. Journal of Food Science. 70: R1-R10