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Abstract

Purpose – The purpose of this study is to review the recent approaches in food packaging trends to address the preferences of the modern world.

Design/methodology/approach – Recent studies in all the emerging food packaging technologies have been discussed with the examples of commercially available products.

Findings – Advanced food packaging solutions have acquired much appreciation from food industries to address the preferences of the modern world. This paper attempts to describe the current practices in food packaging with examples of commercially available products. Significant emphasis has been given on the technical aspects of the intelligent packaging components, namely, barcodes, radio frequency identification, sensors and indicators. Another distinctive area of packaging focused in this review is the importance of bioplastics due to non-degradable nature of synthetic polymers. Three major categories of biodegradable polymers, namely, polysaccharide-based materials, protein-based materials and lipid-based materials, have been discussed along with an insight about sustainable packaging and edible films and coatings.

Originality/value – Changes in the industrial & retail matters and increasing demand for fresh, safe, nutritious food are the factors owing to the new innovations in the packaging sector. Imminent packaging technologies aim at value addition involving the extension of shelf life, prevention of microbial attack, proper moisture barrier, use of carbon dioxide scavengers/emitters, ethylene scavengers, flavor absorbers, freshness indicators, biosensors and release of bioactive compounds during storage.

Keywords Food packaging, Active packaging, Biodegradable polymer, Edible packaging, Intelligent packaging

Paper type General review

1. Introduction

Food packaging is essential because it deals with the safety and quality of the food. The fundamental objective of food packaging is to contain and secure the food in such a way that it satisfies the industrial economic requirements along with consumer preferences, keeps up quality and well-being and limits harmful effects on the environment. Traditional packaging systems perform the primary functions of containment, protection, convenience and communication, but consumer preferences toward quality and safe food with enhanced shelf life have resulted in the development of various new trends in the packaging systems. Protection and communication functions are now being transformed into active and intelligent packaging. One of the important factors in rapid innovations in the packaging sector is the problem of food-borne microbial outbreaks, which require the introduction of antimicrobial effects in the packaging system without compromising the quality of the food (Appendini and Hotchkiss, 2002).

In recent years, concepts of active packaging, intelligent packaging and biodegradable/edible packaging have been developed and successfully applied in food packaging so as to improve the communication, enhance the quality and safety of food, prolong its shelf life, provide indication about wholesomeness and regulate its freshness. Enhancing the shelf life of

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the food involves elimination of various microbial, biochemical and enzymatic reactions by adopting various strategies of temperature control, moisture regulations, addition of chemicals and implementation of an effective packaging system. The transformation from conventional packaging models to novel approaches is due to promising characteristics of recent practices such as sustainability and biocompatibility of biodegradable polymers, monitoring and tracking ability of intelligent packaging and interactive and dynamic performance of active packaging. Major driving forces behind the popularity of emerging innovations in the packaging industry are development of minimally processed foods, strict laws regarding safety and quality of food, modern distribution practices such as online shopping, global retail trends, pollution-related issues with use of petrochemical polymers and rising demand of communicating packages indicating damage and remaining shelf life of the product (Singh *et al.*, 2011). These upcoming changes in the packaging industry will strengthen the economy because of improved shelf life and decline in losses of the products (Vanderroost *et al.*, 2014).

2. Intelligent packaging

Modern and hectic lifestyle of consumers is the driving force of the development of advances in the food packaging technology in terms of convenience and protection. Intelligent packaging refers to the monitoring of the internal and external environment of the package to predict the quality and remaining shelf life of the product better than best before date (Jong *et al.*, 2005). Intelligent packaging is defined as the packaging system that is capable of carrying out intelligent functions such as detecting, sensing, recording, tracing, communicating and applying scientific logic to facilitate decision-making to extend shelf life, enhance safety, improve quality, provide information and warn about possible problems (Yam *et al.*, 2005). It provides valid and accurate information to the consumers about safety, quality and integrity of the package. Out of four basic functions of the package, intelligent packaging performs communication part in a well-efficient manner. These packages detect unsafe foods and identify conditions that adversely affect the quality of the food.

2.1 Indicators

Indicators are qualitative or semi-quantitative devices which provide immediate visual information by means of change in color, deviation in color intensity or diffusion of dye on vertical or horizontal straight path (Kerry *et al.*, 2006). Most of the indicators are irreversible in nature, as otherwise, they may report false information about the product. Indicators have been categorized into three classes, namely, external indicators, internal indicators and indicators that increase the information flow between consumers and product (Pavelkova, 2013). External indicators are connected or attached on the exterior of the package, such as time-temperature indicators (TTIs) and mechanical shock indicators, whereas internal indicators are present inside the package (in the headspace or with the lid), such as pathogen indicators and gas leak indicators (Ahvenainen, 2003). Third category of indicators is those which increase the information flow between package and consumers, such as barcodes.

2.1.1 Time-temperature indicators. TTIs or integrators are smart devices capable of detecting variations in the temperature during transport, handling and storage and can also communicate about product degradation to the consumers. These are self-adhesive labels attached to the package recording and representing partial or full temperature profile of the product. They have been divided into three basic types: critical temperature indicators, critical time/temperature indicators and TTIs or time-temperature integrators (Ghoshal, 2017; Taoukis and Labuza, 2003). Another classification divides TTIs into partial or full indicators (Selman, 1995). Partial TTIs work only after attaining certain threshold value of temperature, whereas full TTIs are independent of threshold value and can respond to any change in temperature. Working principle of TTIs may be biological, chemical or physical depending upon the nature of the label attached to the product, such as melting point temperature, enzymatic reaction, corrosion and solid-state polymerization reaction as a result of whether there is indication in the form of irreversible change in color, visible color development or movement toward some color. Time strip, fresh-check and checkpoint are some of the commercial available TTIs working on the mechanisms such as solid-state polymerization and enzymatic reactions producing results by making changes in the color of the label (Pavelkova, 2013). There is another concept of thermochromic ink, which is a specialized ink that changes its color upon exposure to different temperatures. There are different kinds of these inks, such as cold-activated thermochromic ink, which changes color when the product is cooled, touch-activated thermochromic ink, which becomes transparent on rubbing, and high-temperature thermochromic ink, which changes color below pain threshold, giving warning about safety hazard (Vanderroost *et al.*, 2014).

2.1.2 Freshness indicators. Freshness of a food product is indicated by its chemical and microbial deterioration; thus, freshness indicators indicate the chemical and microbiological spoilage occurred during storage and handling. Information given by freshness indicators is either indirect, such as chemical or microbiological changes in the food cause change in the oxygen concentration of the headspace of the product, or direct, such as the reaction between the freshness indicator label and microbial toxins produced during spoilage. They are internal indicators present inside the package. The microbiological quality of the product can be examined by the reaction between the indicator and the microbial metabolites (Ghoshal, 2017; Smolander, 2003). There has not been commercialization of such indicators in available products, but they have a potential to be widely used for better communication of the freshness and quality to the consumers. Microbial activity in many meat products leads to changes in the concentration of various chemicals such as n-butyrate, D-lactate and acetic acid, which can be potentially used as indicator metabolites produced by microorganisms. pH-based indicators can serve as freshness indicators with change in the color as indication of presence of these metabolites (Shu and Mattiasson, 1993). Various biogenic amines such as tyramine, histamine and cadaverine can be used as indicators of meat freshness as they are produced during meat decomposition (Rokka *et al.*, 2004). Other than quality and deterioration of food, these indicators can also be used in the estimation of remaining shelf life of the product (Kuswandi *et al.*, 2013).

2.1.3 Gas/leakage indicators. Gas composition inside the package is of utmost importance as any variation in it from ideal composition can lead to spoilage of product. Changes in the gas composition occur because of several reasons such as respiration from produce, leakage from the packaging material, permeation through package or gas produced by microbes. Oxygen is the most important gas responsible for the deterioration of the product because it allows aerobic microflora to grow and thrive and also favors enzymatic spoilage reactions. Like others, oxygen indicators must be irreversible in nature and possess other required properties such as it should be non-toxic and only get activated in the presence of oxygen. Oxygen indicators can be divided into two categories: lumophoric and colorimetric. Measurement of luminescence intensity in lumophoric system is considered an indication of presence of oxygen inside the package, which usually decreases with increase in the partial pressure of the oxygen, whereas colorimetric system works on the principle of color change. Change in color can be due to redox reaction, oxygen binding reaction or light-activated redox reactions (Mills, 2005). Oxysense, a luminescence-based indicator system, is the first commercially available oxygen indicator measuring dissolved oxygen inside food packages. These gas sensing devices are present in several forms such as a label, a tablet, printed coating or laminate in a polymer-based film (Rooney, 1995; Vermeiren *et al.*, 1999; Mills, 2005; Ahvenainen, 2003).

2.2 Radio frequency identification

Radio frequency identification (RFID) systems are used to capture, write, store and read the data of the object to which they are attached by the use of radio waves. It has been the most important tool in the category of traceability or antitheft device since long for tracking expensive items, and now its use has been extended toward intelligent food packaging system in the past few years. RFID system comprises two components, namely, transponder, which is attached to object to be identified, and reader, which is used to capture read and write data. Mode of action of RFID tag starts with storing data in tags, which are activated by readers when the object enters the electromagnetic region of the reader, followed by transmission of data for decoding to reader, and the data are then further processed by transferring the decoded data to the computers (Brody *et al.*, 2008). Ilie-Zudor *et al.* (2006) have classified RFID systems into three categories: passive RFID tags, which do not contain any battery and are powered by reader and are simple, cheap and short range; semi-passive RFID tags, which use battery to power the tag to modulate the waves emitted by the reader and to maintain memory of the tag; and active tags, which are battery-powered and are able to broadcast signal to the reader. Active tags have range of more than 100 feet, whereas passive tags have range less than 15 feet (Yam *et al.*, 2005). Simple RFID systems are quite useful in other industries to where only identification, tracking or traceability of the product is required, whereas in food packaging, there is a need to make few improvements to make it more effective and efficient. Thus, sensor-based RFID tags are more popular in food industries, as it is very vital to maintain the quality of produce from farm to plate. Storage conditions such as temperature, humidity, gas composition, light exposure, pH and pressure have considerable effect on the safety and quality of the food products. Thus, monitoring these conditions by incorporating indicators or sensors with RFID tags is required so that complete history of the product about temperature profile, leakage and pathogen detection can be obtained.

The indicators that can be added to RFID tags can be TTIs, gas indicators or microbial/pathogen indicators. The major challenge in the application of sensor-based RFID tags is the integration of one or more sensors/indicators with RFID tag. Sensor-enabled RFID tags have potential applications in storage and transport of perishable commodities such as meat, poultry, fruits and vegetables, which require strict environmental conditions during handling. Potyrailo *et al.* (2012) studied the application of passive RFID tags as sensors for assessment of milk freshness, bacterial contamination and fish spoilage.

2.3 Biosensors

Biosensors are compact analytical tools that can detect, record and/or transmit data or information about biochemical reaction. Generally, biosensors comprise two main components: bioreceptor and transducer. Bioreceptors are mainly biological materials such as enzymes, metabolites, hormones, antibodies or nucleic acids, whose main function is to recognize the target analyte, whereas transducers perform the function of conversion of biochemical signals into electrical response. Transducer can be in several forms such as optical, electrochemical and acoustic or voice. Biosensors work on the principal of interaction between the target analyte and recognition element, because of which variations are observed in physio-chemical properties such as pH, optical properties or electron transference, which are then detected and measured by the transducer. They are able to detect the target analytes in a more effective manner as compared to indictors. They can sense the freshness of food better than freshness indicators and are also comparable with pathogen indicators (Roya and Elham, 2016). For proper functioning, biosensors must possess few important characteristics such as specificity, simplicity, reliability, sensibility and portability.

A suitable example of biosensor in food packaging is a prototype named as Food Sentinal System being developed by Sira Technologies (Pasadena, CA, USA). In this technology, the membrane-forming part of the barcode is attached to a specific antibody, which leads to the detection of the contaminating bacteria because of the development of localized dark bar, which makes the barcode unreadable upon scanning (Yam *et al.*, 2005).

2.4 Barcodes

The Universal Product Code (UPC) barcode consists of pattern of spaces and bars representing 12 digits of data. The major constraint in the UPC barcode technology is that it can store or represent limited amount of information because of its small storage capacity (Yam *et al.*, 2005). In today's scenario, most of the companies are dependent upon the barcode technology for tracking of in- and out-flow of their products. Barcoding system improves the speed of transmission of data and accuracy of the information (Manthou and Vlachopoulou, 2001). In the food industry, barcodes are used in retailing of the commodities mainly in super markets. Because of its meager storage capacity, they are able to store limited information only, such as the price of the product and manufacturing or expiry details. Another category of barcodes, PDF 417 (PDF – portable data file), is a two-dimensional data carrier capable of storing comparatively more information than UPC barcodes. Along with the basic information of simple barcode, additional information can be incorporated in the system. This information includes graphics, nutritional composition, cooking or serving instructions, etc. Because of such limitations, RFID tags are gaining more popularity than barcodes in intelligent packaging of the food commodities. Table I indicates some examples of intelligent packaging.

3. Active packaging

Active packaging refers to the incorporation of some active additives in the package so as to meet the expectations of the consumers and to satisfy them. It is a concept in which the package, active added substances and environment interact with each other and the food

			Examples	
Agents	Function	Principle	Company/ Product name	Food items
Gas indicator	Indicate damage for products packed in modified atmosphere	Chemical, enzymatic, pH dyes, redox dyes	O_2 Sense™Ageless Eye® Tell-Tab	High fat foods or those which have been packaged under reduced oxygen concentration
Freshness indicator	Indicate the time when the product has passed the useful freshness	Chemical, enzymatic	FreshTag®	Sea foods
TTI	Reflect the full or partial temperature profile during transport and storage	Mechanical, chemical or enzymatic	3M MonitorMark™ Timestrip®	Food stored under chilled and frozen conditions
Sensor-enabled RFID tag	Tracing and theft detecting	Electronic	Intelleflex TMT-8500	

Sources: Vanderroost *et al.* (2014); Pavelkova (2013)

Table I. Examples of intelligent packaging components to prolong the timeframe of realistic usability, upgrade the safety of the product and keep up the quality and organoleptic characteristics of the item. Traditional packages are considered to as passive packages which serve as potential barriers to keep the food away from the external environment and to delay the deterioration of the product, while the active packaging is dynamic approach in food preservation as it includes interaction of its various components (Brody *et al.*, 2001; Lopez-Rubio *et al.*, 2004). The different frameworks used as a part of the active packaging change the environment inside the package by addition or elimination of gases in headspace and may likewise interact with the product surface. Either emitters or scavengers are the active components of active packaging solutions. In the accompanying passages, each of these systems is talked about alongside knowledge about their significance and also applications. Some of the common active packaging systems are given in Table II.

3.1 Oxygen scavengers

The oxygen inside the package even at low levels triggers the deteriorative responses and limits the time span of consumption of the item. The different reactions that occur within the sight of oxygen are lipid oxidation known as rancidity bringing about off flavor; accelerating the growth of aerobic microorganisms and molds; oxidation of the pigments present in the food that cause undesirable changes in the color; and degrading nutrients, for instance, degradation of vitamin C. The various ways by which oxygen may be accessible in the package are entrance through packaging material, minor leakage due to poor sealing, on account of air encased in the container, deficient gas flushing or evacuation of the head space (Lopez-Rubio *et al.*, 2004). The oxygen scavenging compounds react with the oxygen present in the package to reduce its concentration and make it unavailable for deteriorative reactions. The most regularly used oxygen scavenger is ferrous oxide (Kerry *et al.*, 2006).

Table II. Active packaging systems with food applications

Active systems	Mode of action/agents used	Applications
Oxygen scavengers	Chemical: conversion of oxygen by catalyst such as platinum, ascorbic acid oxidation, Enzymatic: glucose oxidase glucose, alcohol oxidase-ethanol vapor	Bread, biscuits, snacks, meat, fish, poultry, pizza, cakes, Roasted nuts, coffee, Chocolate, Fruit juice, Ready to drink tea, tomato-based products, smoked meats, fish and sausages
Carbon dioxide scavengers/emitters	Ferrous carbonate-metal halide, iron powder-calcium hydroxide	Cakes, meat, fish, coffee, nuts, peanuts, potato crisps, cheese, beef, poultry products and other snacks
Moisture absorbers	Diatomaceous earth, silica gel	Cereal products, fresh pasta, meat, seafood, poultry, fruits, cheese, and vegetables
Flavor/odor absorbers	Baking soda, active charcoal	Juices, snacks, ice cream, fish and dairy products
Ethylene scavengers	Silica gel-potassium permanganate, silicon dioxide powder, activated charcoal	Horticultural produce (fruits and vegetables), climacteric produce
Antioxidant releasers	Tocopherol, BHA, BHT, ascorbic acid	Cereals
Antimicrobial emitters	Benzoates, propionates, peroxide, sulfur dioxide, sorbates	Dry apricots

Sources: Floros *et al.* (1997); Ozdemir and Floros (2004)

Other compounds are catechol, some nylons, ascorbic acid, sulfites, photosensitive dyes, unsaturated hydrocarbons and enzymes such as glucose oxidase (Brody *et al.*, 2008).

One or more of the mechanisms which are used in the oxygen scavenging is oxidation of ascorbic acid, photosensitive dye oxidation, immobilization of yeasts in solid holders and enzymatic oxidation (Rooney, 1995). Sachets of these compounds are the most widely recognized technique of incorporation in the head space of the package. Other available forms are labels, immobilization or direct incorporation into the closure or packaging material. Incorporation into packaging material is a beneficial technique as it diminishes the negative consumer response and takes out the danger of the accidental rupture of the sachets and prevents the consumption of their contents. Ahvenainen and Hurme (1997) have appraised the advantage of active packaging over modified atmospheric packaging that the capital investment involved is substantially lower, and this is of great significance to small- and medium-measured food companies for which the packaging equipment is often the most costly thing. There are lot of patents where enzymes have been incorporated into the packaging material as oxygen scavenging compounds (Labuza and Breene, 1989). Most widely used enzyme combination for this purpose is glucose oxidase in addition to catalase. Oxygen scavenging labels such as Freshmax (Multisorb Technologies, Inc., USA) and addition of O_2 scavengers in closure seal liners for soft drink and beer bottles, such as Smartcap (a development of Advanced Oxygen Technologies Inc., USA) or OxbarTM (Carnaud Metal Box, UK), are some of the recent commercialized systems used with food packaging (Vermeiren *et al.*, 1999).

3.2 Carbon dioxide emitters/scavengers

Generating carbon dioxide in the packages is a complementary technique to oxygen scavengers as carbon dioxide is known to suppress microbial growth (Suppakul *et al.*, 2003). Carbon dioxide is also used to overcome partial vacuum inside the package caused by oxygen scavengers and also to decrease the rate of respiration of fresh produce (Labuza and Breene, 1989). It is critical to ceaselessly deliver carbon dioxide in the package as its permeability is three to five times more than oxygen in the vast majority of the plastic films. Application of carbon dioxide to suppress the microbiological population is often found in certain products such as meat, bakery products, cheese and poultry (Lopez-Rubio *et al.*, 2004). As indicated by a few analysts such as Véronique (2008), carbon dioxide at levels of 10-20 per cent is successful against spoilage microbes such as *Pseudomonas*, yet there is no noteworthy impact on pathogens such as *Listeria monocytogenes*, *Clostridium botulinum* and *Clostridium perfringens* even at the concentration of 50 per cent or less.

$Ca(OH)_2$ is an active carbon dioxide scavenger which produces $CaCO_3$ on reaction with carbon dioxide. Other carbon dioxide absorbers include potassium hydroxide or sodium hydroxide, silica gel and calcium oxide. Most of the active ingredients (either emitters or scavengers) are commercialized in the forms of sachets. Sodium bicarbonate is used as carbon dioxide emitter in packages. Carbon dioxide emitters are comparatively potential candidates to be used in active packaging solutions.

3.3 Antimicrobials

Antimicrobials either inactivate the microbes or extend the lag phase in the growth cycle, thereby reducing their growth rate (Quintavalla and Vicini, 2002). Packages showing antimicrobial activity contain one of the following: polymers with external antimicrobial agents or structures with inherent antimicrobial properties. Chemical and natural antimicrobials can be used in this framework. Class of chemical antimicrobials include organic acids (sorbic acid, lactic acid, acetic acid, citric acid and propionic acids, their salts and anhydrides), ethanol (effective against bacteria and fungus but not yeast), metals (copper, zinc, titanium, magnesium, gold and silver) and gaseous antimicrobials (chlorine dioxide and ozone), while bacteriocins (nisin, lacticins, pediocins and diolococcin produced by microorganisms) and natural plant extracts (grapefruit seed, cinnamon, horseradish and clove) come under the category of natural antimicrobials. Commercial antimicrobial packages are available in several forms such as extracts (Nisaplin (Nisin), concentrates (AgIONe, AgION Technologies LLC, USA), films (Microgarde Rhone-Poulenc, USA) and integrated ingredients (Kerry *et al.*, 2006).

3.4 Ethylene absorbers

Ethylene is a gas produced by fruits and vegetables during ripening, which acts as plant hormone. It is very evident that ethylene is the potential reason for the undesirable aging of fruits and vegetables during storage. Rate of respiration is a critical factor correlated with perishability of fresh produce. Ethylene accelerates the respiration rate of fruits and vegetables, leading to aging and senescence. Thus, it is important to eliminate ethylene from packages so as to prolong the life of fruits and vegetables. When mature fruits are exposed to ethylene, along with increased production of endogenous ethylene, softening of fruits tissues also occur, resulting in poor quality of the product. Accumulation of ethylene inside the package results in several other deteriorative reactions such as yellowing of green vegetables, bringing about loss of chlorophyll and bitter flavor.

Ethylene scavengers based on potassium permanganate are most popular players among all ethylene absorbers. They are available as potassium permanganate immobilized on any mineral in the form of permeable sachets. Ethylene is oxidized into acetate and ethanol on reacting with potassium permanganate. These sachets are placed in the headspace of the package. Potassium permanganate is not allowed to come in food contact because of its toxicity and purple color. It can also be incorporated into the packaging material. Few examples of ethylene scavengers commercially available are Evert-Fresh (Evert-Fresh Co., USA), PeakfreshTM (Peakfresh Products, Australia) and Orega plastic film (Cho Yang Heung San Co., Korea) (Vermeiren *et al.*, 1999). Table III lists commercially available active packaging systems.

4. Smart packaging

Smart packaging refers to integration of active and intelligent functions in one system. These systems are capable of detecting and controlling the required parameters affecting the quality profile of product. Various systems being explored now-a-days under the category of smart packaging are self-cleaning, self-heating/cooling and self-healing packages.

Self-healing polymers, being one the most predominant smart packages, are capable of recovering their original properties whenever there is any damage (Pei *et al.*, 2016). Two broad classes of such systems are intrinsic and extrinsic self-healing polymers. Extrinsic self-healing polymers work on the principle of vascular heating and capsule healing, while intrinsic are based on chemical/physical molecular interactions at micro/nano or molecular scale (Blaiszik *et al.*, 2010; Zhu *et al.*, 2015; Haghayegh *et al.*, 2016). Another popular concept of smart packaging is self-cleaning systems. They work by controlling the wetting properties with inherent washing characteristics of super-hydrophobic surfaces (Ye *et al.*, 2015). They are generally built up of polymers containing silicon, titania nanoparticles and graphite (Yildirim *et al.*, 2015), which prevent the wetting characteristics of product due to super-hydrophobicity of surface, lower surface tension and reduced contact point (Kumar *et al.*, 2015; Mlalila *et al.*, 2016). Smart packaging in the food industry is at its infancy and offers broad area of further research and exploration in this field.

Name	Category	Form/Agent	Manufacturer	Reference
OS2000®	Oxygen scavenger	Film	Sealed Air Corporation (USA)	Butler (2002)
ATOX	Antioxidant	Film	Artibal SA	Realini and Marcos (2014)
Keplon™	Oxygen scavenger	Sachet	Keplon Co. (Japan)	Brody *et al.* (2001)
Freshpax M	Carbon dioxide-generating/O_2-scavenging		Multisorb technologies (USA)	Smith *et al.* (1995)
Vitalon®G1	Carbon dioxide generator		Toagosei Chemical Co. (Japan)	Vermeiren *et al.* (1999)
Surfacine®	Antimicrobial	Masterbatch	Surfacine Development Company LLC	Realini and Marcos (2014)
Fretek®	Ethanol generator		Techno Intl. Inc. (USA)	Brody *et al.* (2001)
MicroGard™	Antimicrobial	Film	Rhone-Poulenc (USA)	Brody *et al.* (2001)
MoistCatch	Moisture absorbers	Absorbent pads	Kyodo Printing Co., Ltd	Realini and Marcos (2014)
Ageless G	O_2-scavengers/carbon dioxide-generating	Ascorbic acid	Mitsubishi Gas Chemical (Japan)	Smith *et al.* (1995)

Table III. Commercial examples of active packaging

5. Biodegradable packaging

A wide range of synthetic polymers are used in manufacturing of packaging materials, such as polyethylene terephthalate, high-density polyethylene, low-density polyethylene, polystyrene and polypropylene. The major environmental concern arising with the use of synthetic polymers is the pollution-related problem. This is because of their complex time-consuming degradation process. Because of the non-degradable nature of synthetic polymers, they are presently a danger to the earth. Disposal of plastic is not only causing a hazardous negative impact on the environment but also is dangerous to human lives. Plastic waste dumped into soil prevents the growth of nutrients in the soil, thereby reducing its fertility. Animal life is also adversely affected by pollution (air, water and soil) caused by synthetic polymers. At the point when plastics are discarded as litter after use, their breakdown discharges several hazardous chemicals, including heavy metals such as cadmium and lead, causing potential harm to air, water and soil. These petrochemical polymers are also a major threat to marine environment. During the manufacturing of plastic, polymerization of monomers is never complete, there always exists monomers like bisphenol and styrene. When these monomers come in contact with sea water salts, accelerated leaching of bioactive monomer additives occurs, such as colorants, ultra-violet stabilizers and softeners. Although reusing and recycling can be done with traditional synthetic plastics, they require many decades and produce toxic chemicals when decomposed.

Resistance to degradation is the substantial driving force behind the development of biodegradable packaging materials. According to the definition suggested by International Standards Organization, degradable plastics are those which undergo a significant change in chemical structure under specific environmental conditions. Similarly, biodegradable plastics are those which disintegrate because of the activity of naturally occurring microorganisms such as algae, fungi and bacteria. An overview of different sources or ways by which biodegradable polymers can be obtained is shown in Table IV.

Bioplastics comprise whole family of materials with different properties and applications. Bioplastics are defined as materials which are either bio-based or biodegradable. Regarding bioplastics, there is shift in the trend from compostable materials to bio-based plastics. Major groups of commercially available bioplastics are polylactide (PLA), polyhydroxy alkanoates (PHA), cellulose and starch-based films. In a recent survey of European bioplastics in collaboration with nova Institute, bioplastics global market is predicted to rise continuously in coming years (Figure 1). Global production of bioplastics is predicted to grow from 4.16 million tons in 2016 to 6.11 million tons in 2021. Several material and technical innovations are seen in the bioplastics industry. These new bio-based plastics offer enhanced performance parameters such as better breathability, increased strength, reduced thickness and optical parameters. Increased applicability of bioplastics is an effective measure to reduce greenhouse gas emissions.

5.1 Biopolymer-based packaging

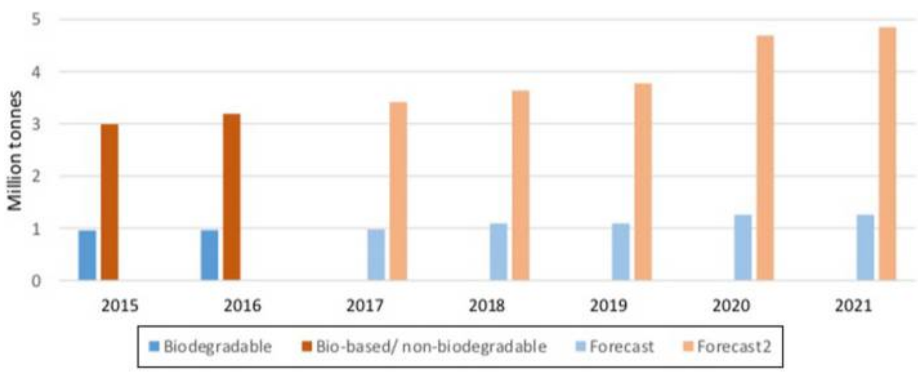
These biopolymers are made up of raw materials originating from marine and agricultural sources. The following three are the basic sources which are potential candidates for the development of biodegradable polymers.

5.1.1 Polysaccharide-based materials. Because of selective permeability toward oxygen and carbon dioxide, polysaccharides hinder the respiration and ripening of fresh horticultural produce. Their wide availability and non-toxic nature makes them suitable for packaging purposes. Starch is one of the most popular biodegradable packaging material. Out of rice, potato, corn and wheat, corn is most commonly used because of its cost effectiveness. The linear fraction of starch known as amylose is responsible for forming

Table IV. Different methods of production of bio-based polymers

Source	Methods	Polymer base/ Examples
Agro resources	Extraction and separation	Polysaccharides and lipids; Starch, cellulose, alginates
Biotechnology	Conventional synthesis	Poly lactides, PE, PBS, PPP
Oil products	Conventional synthesis from synthetic monomers	Polyesteramides (PEA), aromatic and aliphatic copolyesters
Microorganisms	Fermentation	Polyhydroxyalkanoates (PHA), Polyhyrodxy Butyrate (PHB), Polyhydroxyvalerate (PHBV)

Source: Shivam (2016)



Source: European Bioplastics, nova-Institute (2016)

Figure 1. Global production capacity of bioplastics (2016)

strong and free-standing film, unlike brittle and non-continuous film produced by amylopectin (Zobel, 1988). Cellulose and its derivatives are also important natural polymers available for their use in packaging. Cellulose has been used in the packaging of meat with incorporation of pediocin as antimicrobial agent (Ming *et al.*, 1997). Alginates, carrageenan, chitosan and agar are some other polysaccharides successfully used in the packaging of poultry, meat, fish and beef (Field *et al.*, 1986; Cutter and Siragusa, 1996; Meyer *et al.*, 1959; Natrajan and Sheldon, 2000).

5.1.2 Protein-based materials. Protein-based coatings and films are mainly derived from corn, wheat, peanut, gelatin, soybean or milk. Development of these films and their analysis have been done extensively by various researchers (Torres, 1994; Gennadios *et al.*, 1993). In comparison to synthetic polymers, protein-based films show low mechanical strength and poor water resistance. There are several factors such as electrostatic charge and amino acid composition that affect the chemical and physical properties of protein films. Strong cohesive energy density is responsible for brittle behavior, resulting in the risk of cracking. First successful commercial protein-based film was manufactured from collagen. Whey protein isolate/concentrates, soy protein concentrates/isolates and gelatin have been used in developing films for chilled hake, dried fish and frozen salmon (Matan, 2012; Kim *et al.*, 2012).

5.1.3 Lipid-based materials. The packaging film must be flexible and strongly resistant to oxygen and moisture transfer so that it can protect the inside contents in an efficient manner. Polysaccharide and protein-based films have superior mechanical properties but lack good vapor barrier because of hydrophobic nature. Lipid-based polymers possess good moisture barrier properties, but films produced from lipids alone are brittle in nature (Kester and Fennema, 1986). They include lipids of glycerides (esters of fatty acids and glycerol) and waxes (long chain monohydric fatty acids and alcohols). Waxes belong to non-polar lipid class with high hydrophobicity. Carnauba, paraffin, beeswax and rice bran are some of the important waxes applied in coatings in combination with resins and polysaccharides. Major application of monoglycerides in edible films is as emulsifiers. The efficiency of lipid biofilms depends upon degree of saturation, chemical structure and physical state along with homogeneity of the film.

Several bio-based materials which have been used as base material for production of biodegradable films are given in Table V, and Table VI lists the commercially available biopolymers with food applications.

One of the major limitation of bio-based packages is their strength in terms of poor mechanical and water vapor barrier properties (Kumar *et al.*, 2017). In this regard, nanotechnology suggests novel solutions as nanocomposites show better optical, mechanical and barrier properties. Nanoparticles (at scale of 1-100 nm) possesses different characteristics (physical/chemical) in comparison to same composition at the macro level.

Polysaccharides	Protein	Lipid
Citric acid modified pea starch	Zein	Beewax
Carrageenan	Caseinate-pullunan	Wood grease
Corn starch	Whey protein	sugar cane wax
Potato starch	Gelatin	jojoba oil
Chitosan	Peanut protein	bayberry wax
Alginate/pectin	Wheat gluten	paraffin waxes
Cellulose acetates	Fish muscle protein	Rice bran oil
Oat starch	Whey protein	Carbo waxes

Table V. Commonly used materials for bio-film production

Other distinguished improvements in bio-nanocomposites are heat resistance, mechanical strength and flexibility (Mlalila *et al.*, 2016).

6. Sustainable packaging

Although packaging is necessary to protect and distribute the material enclosed, it is considered as burden on the environment because it significantly contributes to environmental waste. Thus, it is the need of hour to frame and implement the concept of sustainable packaging. Sustainable packaging is more promising approach toward the development of an integrated packaging framework. Although it is characterized by several different definitions, all of them include some common features. Four principles defined by The Sustainable Packaging Alliance (SPA), Australia, that sustainable packaging must meet are it must be cost effective and functional, energy efficient, recovery-enabled and non-toxic and non-polluting (Grönman *et al.*, 2013). The ultimate goal of the sustainable packaging is to improve the product performance, which is characterized by several features as given by Sustainable Packaging Coalition in the USA, such as it must be valuable and safe for consumers, encourages the use of renewable material, produced by clean technologies with optimized energy and material and must not cause any adverse effects on environment throughout the food chain from origin to end use. It must hold well on market performance as well. To approach sustainable packaging, it is important not to just deal with product losses but to consider the whole product life cycle of package-product combination by techniques such as life-cycle assessment. Life-cycle assessment is an important tool for analyzing ecological effects of a product, process or activity throughout the lifetime, usually referred as "from cradle to grave" analysis. Global legislation and corporations working with sustainability issues suggest food packaging materials and design to professionals.

7. Conclusion

The packaging sector has led to smart innovations resulting in improved safety and quality. An important area of great interest is to develop the concept of smart packaging, which means integrating intelligent and active packaging together in one system. Such packaging will not only monitor and indicate about the conditions but also will respond according to the requirement. When modern packaging is focusing on delaying microbial and biochemical deterioration, at the same time, a parallel emphasis is done on sustainable packaging. The application of these innovations using bioactivity of functional components is expanding widely because of potential benefits to consumers. Biopolymers reduce the

Table VI. Commercially available biopolymers with food applications

Manufacturing company	Biopolymer film	Food application
KLM	Polylactic acid (PLA) cups	Beverages
ASDA (retailer)	Rigid PLA trays and packs	Fresh cut fruits and vegetables
Cadbury Schwepps	Cornstarch trays	Milk chocolates
Boulder Canyon	Metalized cellulose film	Potato chips
Birkel	Cellulose-based packaging	Organic pasta
Delhaize (retailer)	Paper bags with PLA window	Bread
Wal-MartF	Bio-based trays wrapped with cellulose film	Kiwi

Source: Jabeen *et al.* (2015)

amount of emissions during manufacturing and disposal after end use. These novel technologies in the packaging sector have enabled the packages to perform better than just containment and physical protection. Along with rapid development in the novel food packaging techniques, it is also important to address the issues relating to legislation, testing and privacy to the consumers.

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