Chapter 13
Innovative and Safe Packaging Technologies for Food and Beverages: Updated Review

Ishrat Majid, Mamta Thakur, and Vikas Nanda

Abstract The diverse consumer demand is the main drive for innovations in food packaging. Active as well as intelligent packaging is undoubtedly a huge milestone of the packaging sector in this era extending the shelf life as well as maintaining the food quality. Bioactive packaging, a new approach, has a great role in improving the consumer's health. Nanotechnology like a magical spell has revolutionized the packaging from lighter, more robust, and flexible films to the smart packaging monitoring the food condition. Nanoscale innovations are bringing the packaging area to a brand new unimaginable distinction. The emerging packaging technologies have a monumental influence on several facets of the food segment by minimizing the food wastage, spoilage, food-borne diseases' breakthrough, recalls, and retailer and consumer complaints. This chapter deals with the novel packaging technologies that lower the pathogen detection time, improve the food safety, and control the food packaging and quality all over the supply chain.

Keywords Active packaging · Intelligent packaging · Bioactive packaging · Nanotechnology · Responsive packaging · Microwavable packaging · Edible packaging

Introduction

Food and beverage without a package are unimaginable. Packaging is therefore a necessity for maintaining the quality, safety, and integrity of produce as well as processed products from the farm or plant to the end use. The food and beverage packaging industry has covered a long distance from where it began with the basic carton packaging which was performed with the motive of containment and

I. Majid (✉) · M. Thakur · V. Nanda
Department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology, Longowal, Punjab, India

S. K. Panda, P. H. Shetty (eds.), *Innovations in Technologies for Fermented Food and Beverage Industries*, Food Microbiology and Food Safety,
https://doi.org/10.1007/978-3-319-74820-7_13

transportation only. Traditionally, the major objective of the packaging is food containment; its protection; communication of information like nutritional content, how to use, manufacturer's contact details, etc.; and consumer convenience. However, innovative and safe packaging is the need of time due to the rapid rising consumers' demands towards the fresher, safer, less processed, highly convenient, and prolonged shelf life foods. The current drift of changing lifestyle, eating habits, relentless and extensive competition in market, retail practices, logistics efficiency, and sustainability is the basic driving force behind the requirement of innovative packaging without harming the safety and quality characteristics of food (Dainelli et al. 2008). Further, the food and beverage safety is the main priority given by the current food legislation. The issues of food-borne outbreaks from the past demand the advanced packaging methods to ensure the safety of food.

The recent advances in packaging include active packaging (such as oxygen/CO_2/ethylene scavengers, moisture control agents, etc.), intelligent packaging, antimicrobial packaging, nano-packaging, aseptic packaging, packaging novel mechanisms that regulate the volatile flavours and aromas, advancements in food distribution technology (like electronic product codes and radio-frequency identification), and many more. Active packaging, one of the best examples of innovative packaging, includes basic primary functions of packaging and makes it possible to read, see, feel, or smell the packaged food characteristics. Smart packaging, which is considered as an advanced active packaging, involves the use of sensors. Intelligent packaging which contains indicators/sensors provides us valuable information about the status of food or its surrounding medium (Kerry 2014). It simply accompanies the communication function of conventional packaging and informs the customers about internal or external changes in the product's surrounding.

Antimicrobial packaging that plays a significant part to increase the food and beverage life on shelf is on demand these days due to the microbial contamination leading to health hazard outbreaks. Nanotechnology is offering new opportunities to improve the barrier and mechanical properties of conventional materials and to develop the sensors and novel packaging designs. The use of nanoparticles containing composite materials is considered to be the success of food packaging to control the microbial growth resulting in spoilage. The nanomaterials containing nanoparticles of zinc oxide (ZnO), silver (Ag), and titanium dioxide (TiO_2) have been used recently in the packaging systems. Further, research has been carrying out to explore the potential and safety of use of organic nanomaterials like chitosan and antimicrobial peptides in food packaging. The latest tracking systems are capable of tracking the food packages from the field to fork. A universal product code is being embossed onto the packages for facilitating the checkout as well as distribution control. Recent emerging innovations include sensing the surface variations through the palms and fingertips, any message either sound or verbal, and the odour released under active packaging gamut (Landau 2007).

Active Packaging

Active packaging is typically a supplement of the traditional preservation/protection function of a package conferring the several safety benefits to food products because of the current developments in packaging, material science, and complex consumer desires. Active packaging is generally defined as "addition of definite compounds to the package entity which absorb or release the substances from or into the packaged products or the environment to maintain the nutritional as well as sensory quality while increasing the shelf life and securing the microbial safety of products" (Camo et al. 2008). Active packaging is termed so because package here it is active that it interacts with the food, package, and headspace of the package to maintain the food quality to optimum. The decency of active packaging relies on the inherent characteristics of polymer and incorporation of particular components to the packaging materials (Gontard 2000). It is such that a packaging system offers surplus function besides the protection. It absorbs substances derived from the food or surroundings within the package, or it releases the chemical compounds into the food or surrounding environment like antioxidants, preservatives, and flavourings (EU 2009). And the released components are permitted to be used as food additives.

The application of active packaging-based systems in existing and recently developed food products is novel and ensures that food must reach the consumers retaining their original or enhanced sensory characteristics, with prolonged shelf life and safety which may helpful in reducing the food wastage (Dainelli et al. 2008). Still, the future of active packaging is strongly based on the cost-effectiveness and acceptance for both the consumers and the industry. The most important active packaging systems (adsorbing and releasing systems) used in food products include:

1. Oxygen scavengers/absorbers
2. Moisture absorbers/scavengers
3. Ethylene scavengers
4. Carbon dioxide emitters/scavengers
5. Flavour and odour absorbers or releasers
6. Antimicrobial packaging
7. Antioxidant packaging

Oxygen Scavengers/Absorbers

Oxygen, a key element for supporting the life, however, compromises the food shelf life resulting to degradative oxidation reactions and growth of moulds and aerobic bacteria which cause the quality deterioration by the production of odour, off-flavour, and harmful compounds. It can degrade the vitamin C present in some beverages like orange juice resulting to nutritional losses. Oxygen (O_2) when comes in contact between one and four electrons is reduced to a kind of intermediate compound forming superoxides, hydroxyl radical, hydrogen peroxide, and water among which all are very reactive (free radical in nature) except water resulting in oxidative reactions (Zenner and Benedict 2002).

The quality loss of oxygen-sensitive food products like milk powder, packaged pasta, biscuits, fruit juices, etc. can be reduced using the oxygen scavengers which alleviate the oxygen molecules left after the packaging process (Suppakul et al. 2003). Initially, self-adhesive labels or other adhesive aids and sachets were utilized for the development of oxygen-scavenging systems. However, main problems with the use of sachets are as follows:

- They need extra packing for keeping the sachets to every container/package.
- They cannot be added in case of liquid foods because they lose their activity when wet except ascorbic acid (Day 2008).
- Aqueous slurry of oxygen scavenger is formed in high-moisture foods when moisture introduces into the sachet. The slurry is then discharged onto the food product, ruining its appearance (Yeh et al. 2008).

However, nowadays oxygen-scavenging components are being included within the packaging material itself making use of enzymes, mono- or multilayer substances, and reactive closure liners for jars and bottles.

Commercially, oxygen scavengers are no doubt the utmost significant subcategories of the active packaging and used in the association with vacuum packaging or modified atmosphere packaging (MAP). Oxygen scavengers aid to reduce the permeation of oxygen through the package during storage, transportation, and retail practices. Fast-acting oxygen scavengers are highly efficient oxygen collectors and able to remove oxygen and work indefinitely till the scavengers are present. They are able to remove the oxygen to less than 0.01% as reported by some manufacturers (Vermeiren et al. 2003). This is important in processed meat products like fermented sausages or cooked ham where rapid discolouration may be caused if the package with traces of oxygen is exposed to the lighting causing the photooxidation processes (Coma 2008).

Generally, the oxygen scavengers work on the iron powder oxidation, but nonmetallic oxygen absorbers have been recently developed for minimizing the ill-effects of metal-based scavengers like prospective health issues, causing arc while microwave heating, being detected in the metal detectors, etc. Organic substrates like catechol, ascorbic acid, and polyunsaturated fatty acids are easier to oxidize and introduced into the sachets, labels, and nowadays into the polymer blends (Lee 2014). Some microorganisms such as *Pichia subpelliculosa* and *Kocuria varians* have been included in the oxygen scavengers as an alternative to chemical scavengers which are getting the advantages of maintaining the sustainability. The spores of *Bacillus amyloliquefaciens* were incorporated as scavenger in the polyethylene terephthalate (PET) copolymer having 1,4-cyclohexane dimethanol which can be activated within 1–2 days under the high humidity at 30 °C after which it could efficiently absorb the oxygen for a minimum of 15 days (Anthierens et al. 2011). Also, the enzyme-based oxygen-scavenging systems are also developed where ethanol or glucose oxidase is fused into the adhesive labels or immobilized on the

Table 13.1 Commercially available oxygen-scavenging systems and their manufactures

Oxygen-scavenging systems	Manufactures	Packaging applications	Reference(s)
Oxy-Guard™	Clariant Ltd.	Muscle foods	Clariant (2017)
FreshPax®	Multisorb Technologies, Inc.	Muscle foods	EFSA (2014)
ATCO®	STANDA	Frozen foods	Laboratories STANDA (2017a)
Ageless®	Mitsubishi Gas Chemical Company, Inc.	Frozen foods	Mitsubishi Gas Chemical (2017a)
OMAC®	Mitsubishi Gas Chemical, Inc.	Meat and fish products	Mitsubishi Gas Chemical (2017b)
Cryovac® OS2000	Sealed Air Corporation	Cheeses, meat, baked goods, and dry products like nuts, coffee, and other snack foods	Sealed Air (2017)

film surfaces to retard the rancidity as well as oxidation reactions in the packaged food like chilled fish (Day 2003). It has been found that addition of unsaturated functional groups in the polymer films significantly improve their oxygen-scavenging power (Ferrari et al. 2009). Oxygen-scavenging systems comprising the nature-derived free radical scavengers such as ascorbic acid/α-tocopherol and a metal don't need to be activated using UV light which is otherwise needed if metal is used alone.

For commercial applications, the oxygen scavengers are usually introduced to the packaging materials to exclude the nonedible waste along with the food, reducing the uncertainty of sudden rupture or crack of the sachets in the package and consumption of their contents (Suppakul et al. 2003). Some of the commercially available oxygen-scavenging systems based on the sachet is given in Table 13.1.

Moisture Scavengers/Absorbers

In case of foods with high water activity, surplus moisture is formed within the package resulting in the bacterial and mould growth which leads to the reduction of shelf life and food quality. Therefore, moisture scavengers are necessary for controlling the moisture formation to prevent microorganism growth and improve the product appearance (Ozdemir and Floros 2004). After oxygen absorbers, moisture scavengers are the commercially developed category and available in various forms like pads, sachets, sheets, or blankets.

Desiccants like activated clays, silica gel, calcium oxide (CaO), and other minerals are generally porous and tear-resistant plastic-based sachets which are used to control moisture and humidity in case of dried food packaging. The best known moisture scavengers are conventional silica gels that can absorb approximately 35%

Table 13.2 Commercially available moisture-scavenging systems and their manufactures

Moisture-scavenging systems	Manufactures	Packaging applications	Reference(s)
Cryovac®Dri-Loc®	Sealed Air Corporation	Meat and fish packaging	Sealed Air (2017)
MeatGuard®	McAirlaid Inc.	Meat, fish, and soft fruit packaging	McAirlaid (2017)
Nor®Absorbit	Nordenia International AG	Microwavable susceptors and packaging	Nordenia (2011)
Fresh-R-Pax®	Maxwell Chase Technologies	Fresh-cut fruits	Maxwell Chase Technologies (2017)
TenderPac®	SEALPAC GmbH	Meat products	SEALPAC (2014)

of their own weight in water and maintain the water activity less than 0.2. On the other hand, molecular sieves like zeolites may pick up to 24% of their weight in water and also absorb odours, when dry. Nowadays, moisture drip-scavenging sheets, pads, and blankets are being synthesized by many companies to control the moisture in foods with high a_w like fruits, vegetables, meats, poultry, and fish. Such absorber typically consists of a double layer of microporous non-woven polymer like polyethylene (PE) or polypropylene (PP) which is located onto the super absorbent compounds like starch-based copolymers, carboxymethyl cellulose, and polyacrylate salts. These materials are commercially found in the form of different size sheets, employed as drip-absorbing pads and typically observed in tray configured either overwrap or in case of modified atmosphere packaging of muscle foods (Kerry et al. 2006). These drip scavenger pads are usually fixed below the packed fresh meat, fish, and poultry to suck in the hideous tissue drip exudate. Massive sheets and blankets are employed for air transportation to absorb the melted ice discharged from chilled seafood and control the transpiration in fruits and vegetables. These scavengers can also be used with (i) activated carbon to absorb the odour or (ii) iron powder to absorb the oxygen thus exhibiting dual action. Likewise, the double-action carbon dioxide (CO_2) or oxygen absorber sachets and labels are employed commercially for the foil packaged and canned coffee in the USA and Japan (Rooney 1995). Some commercially available moisture-absorbing pads are enlisted in Table 13.2.

Ethylene Scavengers/Absorbers

Horticultural produce releases the ethylene (C_2H_4), a ripening hormone, after their harvesting. Ethylene initiates and then fastens the respiration rate leading to senescence which softens the tissues, increases the degradation of chlorophyll, and decreases the shelf life of raw and minimally processed vegetables and fruits (Knee 1990). Therefore, control of ethylene accumulation while storage is critical to enhance the post-harvest life and to preserve the organoleptic quality of produce as well as processed products. In such cases, ethylene scavengers are employed to absorb the emitted ethylene and to preserve the ethylene-susceptible vegetables and fruits like mangoes, apples, onions, tomatoes, bananas, and carrots.

The most widely used and inexpensive ethylene scavenging system comprises of strong oxidizing agent potassium permanganate (4–6%) embedded onto the carrier (inert) having enormous surface area like alumina pellets, celite, vermiculite, silica gel, activated carbon, perlite, or glass for improved effectiveness (Zagory 1995). Potassium permanganate changes its colour from purple to brown upon oxidation, and therefore ethylene scavenging capacity is indicated by the colour change. Other kinds of ethylene scavenging system are dependent on:

1. Adsorption of ethylene either alone or in combination with other oxidizing agent. For example, palladium exhibits higher ethylene scavenging ability under higher relative humidity than the absorbers containing potassium permanganate (Smith et al. 2009).
2. Adsorption and then disintegration of ethylene into activated carbon. Such adsorbing technologies typically rely on the incorporation of precisely fine minerals like zeolites, Japanese oya, and clays into the films (Zagory 1995).

Ethylene scavenging systems are available in the market alone or combined with package. Retarder® and Ethylene Control Power Pellet are the commercially available ethylene scavengers based on potassium permanganate. They are available in the market as a sachet or inserted in the polymer as finely dispersed minerals. Ethylene absorption by zeolites placed in a polymer is found in PEAKfresh® and Evert Fresh Green Bags® scavenging systems (de Abreu et al. 2012).

Carbon Dioxide (CO_2) Scavengers/Emitters

Carbon dioxide (CO_2) is toxic to the growth of aerobes (bacteria or fungi) due to the decreased relative oxygen level and antimicrobial effects which result in the prolonged lag phase as well as generation period in the log phase during the growth of microorganisms. High carbon dioxide levels (nearly 10–80%) find applications in meat preservation for the inhibition of surface growth of microorganisms and thus increasing the storage life (Kerry et al. 2006). Hence, carbon dioxide emitters are considered like a supportive system to oxygen scavengers (Suppakul et al. 2003). Aerobic bacteria like *Pseudomonas* may be prevented by using the medium to high levels (10–20%) of CO_2, while the lactic acid bacteria reproduction may be triggered by the CO_2. Moreover, several pathogens like *L. Monocytogenes*, *C. botulinum*, and *C. perfringens* are partially inhibited by the concentration (<50%) of carbon dioxide. A study reported the increased production of *C. botulinum* at higher CO_2 levels while reducing the bacterial growth rate (Lövenklev et al. 2004). Hence, application of CO_2 packaging must be precisely scrutinized depending upon the various meat products and CO_2 levels.

The carbon dioxide scavenger removes the carbon dioxide from package headspace irreversibly resulting in depletion of CO_2 that is not always desired. An oxygen scavenger and carbon dioxide emitter can be used in combination for food products where appearance and volume of package are important because they prevent O_2 absorption resulting in the collapse of package. In modified atmosphere packaging (MAP), carbon dioxide usually has a microbiological inhibitory effect, but surplus levels of carbon dioxide may adversely affect the product (sometimes change the taste of product). Hence, it is necessary to remove the carbon dioxide in some packaging systems to ensure the food preservation. Calcium/sodium/potassium hydroxide, silica gel, and calcium oxide are widely used as CO_2 absorber to inhibit the package cracking (Ahvenainen 2003). At high water activity conditions, the calcium hydroxide combines with carbon dioxide to form the calcium carbonate:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

CO_2 emitters are applied mainly to decrease the gas to product (gas-product) volume ratio resulting to lowered headspace. They are commercially employed as the absorbent pads and sachets in meat, poultry, and cheese packaging (Realini and Marcos 2014). Several commercially available CO_2 emitters are based on the mixture of sodium bicarbonate (Na_2CO_3) and ascorbic acid or ferrous carbonate ($FeCO_3$) such as:

1. Verifrais™ from SARL Codimer, France
2. Ageless G from Mitsubishi Gas Chemical Co., Japan
3. FreshPax M from Multisorb Technologies Inc., USA

CO_2 Fresh Pads™ (CO_2 Technologies, USA) and SUPERFRESH system containing CO_2 emitter coated polystyrene box (Vartdal Plastindustri AS, Norway) are employed for the packaging of meat, poultry, and seafood to increase their shelf life and reduce the environmental impact and transport volume (Realini and Marcos 2014). In the case of CO_2® Fresh Pads, the mats absorb the liquids exuded from the food products, and liquids combine with the sodium bicarbonate and citric acid to produce carbon dioxide.

Flavour and Odour Absorbers or Releasers

The incorporation of odours and flavours is basically employed to make the food more appealing to the consumers and enhance the aroma or flavour of fresh food or processed product on opening the package. Such aromas and essences are generated gradually and uniformly inside the packed product during its storage life, or their spread may be regulated while food preparation or opening the package. Slow distribution of aroma can be used to balance the inherent loss of smell or taste of food during the entire storage life (Almenar et al. 2009).

On the other hand, the odour removal from the package interior can be detrimental and advantageous also. In earlier case, the absorption of aroma components can withdraw the desired constituents from the product because occasionally the aromatic compounds are naturally accumulated in the interior of the package like in the case of orange juice. In such conditions, the loss of desired aroma must be prevented from the food product which is also one of the objectives of the barrier packaging. However, the removal of odour or aroma is beneficial several times under the domain of active packaging. Some food like cereal products and fresh poultry produce the particular odour called as confinement odour. Some off odours like sulfurous compounds obtained from the breakdown of protein/amino acid or aldehyde/ketone constituents obtained from the lipid oxidation or anaerobic glycolysis are sometimes formed in very less but yet detectable concentration during the product distribution. Such odours are confined within the gas barrier packaging, and they are released when the package is opened and detected by consumers. These odours don't necessarily mean any major food spoilage and are usually harmless but still are rejected even they dissolve into the surroundings. The major cause for their removal from package interior is to prevent or eliminate the potential side effects of these confinement odours. Other possible reason for introducing odour scavengers may be to remove the effect of odour produced in the package materials.

Antimicrobial Packaging

Antimicrobial packaging means the package itself possesses the self-sterilizing capability and thus exhibits a critical role in the packaging of perishables such as meat, fish, poultry, and horticultural produce because they provide all the nutrients required for the microbial growth. This packaging thus helps in reducing the multiplication of pathogenic microbes like *L. monocytogenes*, *Salmonella* spp., *S. aureus*, *C. botulinum*, *C. perfringens*, and *E. coli* O157:H7 to enhance the shelf life and confirm the delivery of safe wholesome food to final consumers (Jayasena and Jo 2013). It lengthens the lag phase and minimizes the log phase of the growth cycle of microorganisms to preserve the food. Basically, antimicrobial packaging can be categorized into four classes as:

1. Direct introduction of antimicrobial compound(s) into the polymer film
2. Addition of antimicrobial pad/sachet inside the package
3. Use of innately antimicrobial polymer
4. Coating the packaging film with a matrix

Several antimicrobial compounds comprising carbon dioxide, ethanol, chlorine dioxide, silver ions, antibiotics, organic acids, peptides, bacteriocins (nisin), spices, plant extracts, and essential oils were examined to inhibit the growth of microbes in foods (Suppakul et al. 2003). The effectiveness of antimicrobial packaging is affected by various factors like:

1. Choosing an effective delivery method
2. Selection of suitable antimicrobial substance
3. No/negligible effect on the organoleptic characteristics of packaged product

Nowadays, lactic acid bacteria-based bacteriocins which are basically hydrophobic, cationic, and amphiphilic peptides are widely used as an antimicrobial agent mainly to Gram-positive bacteria. Antimicrobial packaging using nisin is being utilized to inhibit the multiplication of lactic acid bacteria on the beef burger kept at 4 °C and thus enhance its shelf time (Ferrocinoa et al. 2016). Nisin exerts synergistic effect when used with other preservatives. Nisin in combination with potassium sorbate produces the synergistic effect against *Listeria innocua* and *Zygosaccharomyces bailii* in vitro when added in tapioca starch hydroxypropyl methylcellulose films (Basch et al. 2013). A study conducted by Jofré et al. (2008) reported that sliced cooked ham when vacuum packaged using interleavers carrying nisin (200 AU/cm^2) and potassium lactate (1.8%) was more strongly protected against the growth of *L. monocytogenes*. However, the major limitation regarding the commercial use of nisin extract is the low concentration (e.g. 2.5%) of nisin (Royal DSM, Delvo® Nis, Nisaplin®, and Danisco) which means a huge quantity of extract is required to get the desired antimicrobial effect. Additionally, various semi-purified bacteriocins are also used as an antimicrobial agent because bacteriocins are basically the natural compound obtained from the bacterial growth. Enterocins obtained from *Enterococcus faecium* are applied in meat products to regulate the growth of *L. monocytogenes* (Marcos et al. 2007). Lactocins when used as an antimicrobial film decreased the growth of *L. innocua* on the surface of wiener sausages (Blanco et al. 2014). Most recently, live bacteria can be employed to introduce the bacteriocins into antimicrobial packaging. Further, bacteriocin-containing packaging films may be combined with the novel processing technique such as high pressure processing (HPP) to decrease of microbes more effectively. Laboratories STANDA has developed SANICO®, an antibiotic (natamycin)-based antifungal coating employed for sausages (Laboratories STANDA 2017b). The nisin/polylactic acid (PLA) films were developed by Jin and Zhang (2008) for their use either as packaging material for bottles or coating on the surface of bottles to minimize the microorganism's proliferation in fruit juice packaging.

Nanotechnology can improve the antimicrobial packaging using nanoparticles which possess the increased area than traditional antimicrobial compounds and thus reduce the quantity of antimicrobial substances because of magnified antimicrobial activity of nano-compounds. The cellulose/silver nanocomposites reduced the harmful moulds and yeasts up to 99.9% in kiwi and melon juices which verified the antimicrobial activity of silver-based nanoparticles (Lloret et al. 2012). A wide range of silver-based antimicrobial master batches can be seen in the market like Agion®, Bactiblock®, Biomaster®, d2p®, IonPure®, Irgaguard®, and Surfacine®. Addmaster and LINPAC Packaging Ltd. joined hands together for the development of antimicrobial trays and lids with the Biomaster®, a silver-containing additive so as to retard the multiplication of pathogenic organisms like *Salmonella*, *Campylobacter*, and *E. coli* in the fresh meat (LINPAC 2012, 2017). Sodium alginate film which carries zinc oxide nanoparticles removed the *Staphylococcus aureus* and *S. typhimurium* in RTE poultry meat (Akbar and Anal 2014).

Further, a new trend of phenolic compounds' incorporation to essential oils like thymol, eugenol, and carvacrol has attracted huge attention for possessing natural antimicrobial activity against meat-based products (Jayasena and Jo 2013). The basic mechanism behind these compounds' antimicrobial action is the increase in permeability of microbial cell membranes which causes the loss of cellular ingredients. Recently, the encapsulation of essential oil combined with other components like nisin, MAP, and lysozymes into the nano-emulsion are being used in the meat sector to improve the safety and organoleptic properties of meat and other processed products (Jayasena and Jo 2013).

Antioxidant Packaging

Oxygen in excess concentration may promote the lipid oxidation especially in animal products, microbial growth, and development of nutritional losses, colour changes, and off-flavours/odours. The oxidation of lipids leads to the rancidity development and forms the poisonous aldehyde compounds thus deteriorating the nutritional quality due to the degradation of polyunsaturated fatty acid (PUFA). Likewise, various oxidative reactions in the food products are the main cause for quality deterioration. Therefore, the antioxidant agents can be incorporated in the package to remove the oxygen for increasing the storage life, besides using oxygen scavengers. Antioxidant packaging has several following advantages than the direct addition of antioxidants:

1. Very low amount of active compounds needed
2. No need of additional steps like spraying, mixing, or immersion
3. Modulated antioxidants' release
4. A confined activity

However, the addition of antioxidants can influence the various quality attributes like taste or colour, and thus the consumer preference is required for the exclusion of additives in foods.

Several antioxidant compounds are introduced successfully in diverse forms like labels, coating, and sachets, and are added into the polymer matrix or immobilized on polymer surface in the package to prevent oxidative reactions occurring in food. Recently, the major trend is to use natural antioxidant compounds like tocopherol, ascorbic acid, and herb-derived essential oils like tea, rosemary, oregano, and plant extracts thus minimizing the use of synthetic additives. The blue shark muscles packed in the polymer film containing the barley husk-derived natural antioxidant had exhibited the reduced oxidative degradation (de Abreu et al. 2011). Similarly, the lipid oxidation was decreased to 80% in beef packed with films carrying the natural extract obtained from residual waste of brewery (Barbosa-Pereira et al. 2014). Cocoa extract carrying active films have been reported by Calatayud et al. (2013) which possesses both antioxidant and antimicrobial characteristics. Nowadays α-tocopherol a natural antioxidant has been added into polylactic acid

(PLA) films (a versatile compostable polymer) as an antioxidant packaging material (Jamshidian et al. 2012). Recently extensive research is being conducted for combining the antioxidant packaging with other novel processing treatments like HPP to improve the food quality and safety (especially meat-based products) (Marcos et al. 2008).

The antioxidant action of polymers is based on the migration process where the components released must meet the maximum allowable concentration and must be permitted as food additives. However, antioxidant packaging systems may be best effective when antioxidant release rate would be fitted with the rate of lipid oxidation (Lee 2014). The diffusion-based mathematical models can be a suitable technique to determine the profile of antioxidants' release into the food and beverage. But more research work is necessary to regulate the rate of bioactive agents' diffusion in the practical packaging systems while on storage.

Other Active Packaging Systems

Ethanol emitters are another category of active packaging systems which suppress the growth of bacteria and yeasts and are mainly effective against mould. Ethanol emitters are mainly employed in the sachet form extensively for high-moisture bakery products like cakes and cheese to make them mould-free and extend the shelf life by 2000%. In food packages containing sachets of ethanol emitters, the water molecules are absorbed by the food; ethanol vapours are released and thus diffused into the package headspace (Day 2003).

Temperature-controlled active packaging systems utilize the novel self-cooling/heating cans and insulating substances to reduce or eliminate the disproportionate temperature abuse while on transportation as well as storage of frozen and chilled foods. One such kind of insulating material is Thinsulate which contains several air openings. The chilled temperature can be regulated by increasing the package thermal mass which enables the package to tolerate the temperature increase. Self-heating containers and cans consisting of aluminium and steel are heated using an exothermic reaction which takes place on the mixing of lime and water positioned in the base and have been available commercially from decades for sake, tea, coffee, and ready meals mainly popular in Japan. The latent heat produced during water evaporation creates the cooling effect and this principle was exploited by CROWN Packaging Europe GmbH, Switzerland, in association with Tempra Technology, Inc., Florida, to develop a self-chilling beverage can (Tempra Technology™ 2017).

Nowadays, the convenient foods are high in demand due to which the microwave heating has become a trend in food outlets and household. However, heat transfer in microwave heating produces the varying energy absorption which results in the irregular distribution of temperature in the food products. Therefore, the microwavable active packaging aims to improve the heating performance of food using the field modification, susceptors, and shielding (Regier 2014). The modifiers comprised of a sequence of antenna structures thus altering the path through which microwaves reach to the food resulting in uniform crisping, heating, and surface browning (Ahvenainen 2003). Shielding may be used to obtain more uniform heating and regulated distinct heating of several food segments. On the other hand, microwave susceptors are made of stainless steel or aluminium accumulated on the substrates like paperboard or polyester films and used to crisp, dry, and finally brown the microwave food (Perry and Lentz 2009). Commercially available microwave susceptor is Sira-Crisp™susceptors (Sirane Ltd.) (Sirane 2011) whose application lies in the heating of hot dogs, sandwich, frozen entrees, or meat pies as the meat-containing foods.

Organoleptic alterations in the food products are due to the intended or non-intentional interactions between the polymer and product and sometimes due to the unsuitable medium characteristics essential to protect the food quality. In such kind of case, taste and smell emitters are the fascinating solution. The emitters of smell uniformly spread the scent masking fragrant compounds in the packaging systems and improve the natural aromas of the product and attract the consumers to buy the product again. Such compounds are identified by the very low thermal conductance and used as additive to polyamide, polyester, polyethylene, polypropylene, and polyvinyl chloride.

Intelligent Packaging

The intelligent packaging may be defined as "the packaging system which performs the multiple intelligent tasks like identifying, tracing, sensing, recording and communicating the information to increase the safety, quality, shelf life, and alert regarding the possible problems". An intelligent package traces the product, senses the external/internal conditions of the package, and informs the consumer about product health thus monitoring the quality and safety of food and beverage, while active packaging system takes some action (like scavenge the oxygen or moisture) to protect the product. An intelligent packaging system contains small and inexpensive smart devices either tags, sensors, or labels that acquire, store, and transfer valuable information regarding characteristics and functions of food products. The frequently employed smart devices for such kind of packaging are discussed as:

Barcode

The barcode is an optical machine-based comprehensible symbol and strongly concerned to the device being attached. The universal product code (UPC) was established in the 1970s and was the first successfully commercialized barcode which now has omnipresence in the grocery stores for effective stock reordering, inventory control, and checkout. The UPC barcode has a straight indication comprising of specific arrangement of spaces and bars for expressing the 12 numerals of data carrying particular and confined data like item number and manufacturer identification number (Yam et al. 2005).

Recently, innovative barcode symbologies like two-dimensional (PDF 417, Aztec code), Composite Symbology (a 2D barcode like PDF 417 containing a straight barcode such as UPC), Reduced Space Symbology (RSS), and Family of GS1 DataBar have been developed to meet the emerging need to encode more data in very small space (Uniform Code Council 2017). Information about lot/batch number, packing date, package weight, nutritional information, how to use, and website address of manufacturers can be encoded in barcodes. This information is even readable by the smart phones thus offering great convenience for retailers and consumers.

Radio-Frequency Identification (RFID)

RFID technology also carries the electronic information like barcodes but is more advanced data carrier for product identification having various novel properties like huge data storage capacity (for high-end RFID tags up to 1 MB) and non-line of sight capability, while collection of the real-time data and data may access the non-metallic substances for automatic and fast identification of the multiple product (Mennecke and Townsend 2005). This technique employs tags attached to any package/cattle/pellets, etc. to communicate real-time correct information to the receiver's information system. It has several advantages in the stock management, traceability of product, labour saving expenses, security and improvement of safety, and quality. However, RFID tags are not exactly the substitute of barcode due to its comparatively higher cost and requirement for more strong and efficient electronic information network.

The RFID tag consists of a very small transponder and antenna with distinctive alphanumerical or number sequence. A reader releases the radio wave to record the data from the RFID tag which is then transferred to the host computer using real-time database server for decision-making and analysis. The real reading limit is based on several factors like strength of reader, frequency of operation, and potential intervention from various metal objects (Yam et al. 2005). The tags with low frequency, about 125 kHz, are usually economical, have better penetration through non-metallic items, and consume less power.

Advances in RFID technology involves the combination of TT sensors and RFID devices resulting in the improvement of food supply chain and increased funds because of the low generation of waste. Few reusable TT sensor tags which were developed for providing the information about the history of product based on the real-time temperature through cold chain include the Easy2log© (CAEN RFID Srl), Sensor Tag CS8304 from Convergence Systems Ltd., and also TempTRIP Sensor Tag from TempTRIP LLC (CAEN RFID 2017; CSL 2017). Recently, the RFID tag integrated along with the optical oxygen indicator containing a platinum octaethylporphyrin membrane and a complete electronic-based system had been invented, and interestingly all were printed on the flexible substrate. This whole system was ideal for use in MAP applications in which oxygen level is lowered to less than 2% (Martínez-Olmos et al. 2013). Georgescu et al. (2008) employed the acoustic wave devices in the RFID system including a ID, an electronic module, various passive surface acoustic wave sensors, and printed antenna which observes several chemical and physical parameters of contents through the food supply chain. Sen et al. (2013) reported a monitoring system which consisted of temperature sensor, RFID tag, gas sensor, reader, and server to determine the freshness of pork. RFID has found great application in the packaging of meat-based products where tags may be concealed by meat and thus suitable for scanning of products with high moisture content. Recently, it is being adopted by several dominant companies like Marks & Spencer, Walmart, and 7-Eleven.

Time-Temperature Indicators (TTI)

The time-temperature integrator/indicator (TTI) is an easy-to-use, simple device affixed to the individual package or shipping containers as self-adhesive label which monitors, records, and displays the quantifiable time-temperature-based changes representing the partial or full temperature record of a food product mainly frozen or chilled throughout the food chain thus ensuring product quality and safety.

The fundamental principle of TTIs is to identify irreversible responses of chemical, electrochemical, mechanical, microbiological, or enzymatic changes in the food product at higher temperatures (Kerry et al. 2006). Further, the response level (real time-temperature history) strongly relies on the type of indicator and its working principle. Commercially, there are three types of TTIs based on the response mechanism where irreversible and temperature-dependent enzymatic, chemical, or microbiological changes make the response:

1. Critical temperature indicator which indicates the exposure of product below or above reference temperature
2. Partial history indicator that shows the exposure to a temperature enough to affect the food quality or safety
3. Full history indicator which communicates the consistent response based on the temperature during the history of the product

Currently, some marketed TTIs include CheckPoint, 3M MonitorMark ®, ColdSNAP Temperature Recorders, ShockWatch, ThermRF Logger, Fresh-Check®, Timestrip®, VarioSens®, WarmMark Time-Temp tags, and many more. 3M Company uses a TTI called 3M Monitor Mark® which consists of a mixture containing the esters of fatty acid containing the preferred melting point as well as blue dye. When temperature reaches above the critical value, the substance starts melting and diffuses via the indicator making the blue colour to visualize.

TTIs can be combined with RFID tags or barcodes to generate simpler and efficient time temperature history that can be associated with other food products' data. A TTI Smart Barcode, FreshCode™, is one such device which contains standard barcode as well as senses and stores the temperature abuse through the cold chain. A time-temperature indicator based on the lactic acid was produced by Wanihsuksombat et al. (2010) to observe the food quality where diffusion of lactic acid causes colour changes (from green to red) due to pH reduction and temperature dependency which was identified from 4 to 45 °C. VITSAB® (VITSAB International AB) is TTI dependent on an enzymatic reaction in which alteration of colour from green to clear yellow takes place because of enzymatic hydrolysis of the substrate (VITSAB 2015). Ciba and Freshpoint™ jointly launched the OnVu™ which contains a pigment called benzopyridines which change the colour at temperature-based rates with time. The indicator turns to the dark blue colour when exposed to UV light and starts to fade the colour slowly (Freshpoint 2017b; O'Grady and Kerry 2008).

Gas Indicators

Gas indicators are the devices which can be printed on the polymer films or exist as a label to sense any alternation in the make-up of gas mixture due to package nature and activity of the food like respiration and gas production by growth of microorganisms thus monitoring the food quality, safety, and integrity. Gas indicator causes the change in colour on the packaging to show the gas composition changes, quality degradation of MAP foods, and spotting the poor sealing. A commonly used gas indicator is oxygen indicator due to its side effects on quality of food through oxidative rancidity, microbial spoilage, and colour change. The UV light-activated reusable and irreversible oxygen indicators had been developed by Lee et al. (2008) that consisted of a mixture of an encapsulating polymer like hydroxyethyl cellulose, a redox indicator-like methylene blue, UV-absorbing semiconductor like TiO_2, and an electron donor like triethanolamine; this mixture is being mixed with water to produce ink. The coating/printing of ink on substrates turned them to colourless oxygen indicator film from being blue-coloured on the exposure to UV light. This colourless film is then reoxidized to the original blue colour when it came in contact with oxygen. Likewise, the oxygen indicator named Ageless Eye® has been developed by the Mitsubishi Gas Chemical Company that can be placed inside the container. If oxygen level will be more than 0.5%, the indicator turns its colour from pink to blue. The simple UV-activated inkjet-printed oxygen indicator was reported by Lawrie et al. (2013). Nano TiO_2 powder when mixed with oxidation-reduction dyes, electron donors, and packaging polymers had the potential to trace the oxygen concentration in MAP meat products (Liu et al. 2013).

Further, the gas indicators for other gases like CO_2, H_2S, ethanol, water vapour, and several supplementary gases have been found in literature. The CO_2 indicator is made up of redox indicator dye and calcium hydroxide ($Ca(OH)_2$) incorporated to the polypropylene (PP) and employed for the estimation of fermentation level in kimchi products during supply chain (Hong and Park 2000).

Freshness Indicators

Freshness indicators are the devices showing the degradation and loss of freshness of packaged goods and more beneficial for quality control of packed fruits and meat products. These are dependent on the traditional knowledge of food quality which shows the metabolic products such as organic acids (especially lactic acid), glucose, volatile nitrogenous components, ethanol, biogenic amines (like cadaverine, tyramine, histamine, putrescine, etc.), ATP degradation products, CO_2 and sulfuric compounds linked with spoilage flora, type of meat products, storage conditions, and packaging type. Most of freshness indicators work via colour change in the substrate because of the presence of abovementioned compounds during loss of freshness of products.

The chitosan film containing anthocyanin was employed to develop the colorimetric pH indicator that is used to indicate the formation of microbial growth metabolites like lactic acid, D-lactate, acetic acid, and n-butyrate (Yoshida et al. 2014). In the case of fish, the volatile amines may be used as freshness indicator because trimethylamine oxide degrades into the volatile amines and produce fishy odour and flavour (Etienne and Ifremer 2005). The optoelectronic nose comprising the seven perceiving compounds is manufactured using the chromogenic reagents as well as pH indicators and is employed in the monitoring the pork sausages quality (Salinas et al. 2014).

The recent emerging solution for supervising the food freshness is to develop and use the biosensors for the determination of specific metabolites which are originated during the food spoilage. A biosensor was developed by Pospiskova et al. (2012) to detect the traces of basic nitrogen compounds and biogenic amines produced during microbial metabolism. Further, biosensors can be integrated to the packaging polymer using molecular imprinting technology to generate the recognition compounds for specific analyte molecules which are introduced in prepolymeric mixture to bond with prepolymer. Then, prepolymeric mixture is polymerized using analyte molecule to produce the polymer with the removal of analyte molecules at the end leaving the analyte molecule's shape cavities behind. Like this the specific compound is detected as the cavity shape is particular to the modelled molecule. Thus, an inexpensive packaging material was invented to show the spoilage of meat using the variations in colour (Johns Hopkins University Applied Physics Laboratory 2014).

However, the major limitation with commercialization of freshness indicators is the reluctance of food processors to utilize these indicators for determining freshness because this may harm their image in market, if products are not fresh.

Pathogen Indicators

Pathogen indicators are usually the biosensors which detect, record, and show the information about the biochemical reactions or simply contamination by the pathogenic microorganisms. These are composed of a bioreceptor (biological or organic compounds like antigen, microbe, enzyme, hormone, or nucleic acid) that identifies the target analyte and a transducer (electrochemical, optical, or calorimetric) which produces measurable electrical response from the conversion of biochemical signals and changes the colour to warn the consumers.

A sensor consisting of cross-polymerized polydiacetylene molecules may react with toxin like *E. coli* O157 enterotoxin to change the blue colour of film permanently to red (Smolander 2000). Food Sentinel System™, a commercially used pathogen indicator, has been developed by SIRA Technologies, USA, in which an antibody particular for the target pathogens like *L. monocytogenes*, *E. coli* O157:H7, *Salmonella* sp., etc. associated with the membrane forming a part of barcode along with pathogen organisms if present generates a confined dark bar making it difficult to read the barcode on scanning. A pathogen indicator named Toxin Guard™ was launched by Toxin Alert, Canada, which was composed of biochemical sensors introducing the antibodies to trace the pathogens like *E. coli*, *Listeria* sp., *Salmonella* sp., and *Campylobacter* sp. in polyethylene (PE)-based packaging (Bodenhamer 2000). A novel packaging employs the vanillin, a colorimetric reagent, to detect the microbial growth in several products via visual signal without any direct contact between detection system and microorganism or product (De La Puerta et al. 2010).

Integrity Indicators

The time indicators are the simplest integrity indicators which contribute useful data regarding the duration for which a food product has been opened. These indicators in the form of label activate on breaking the seal by triggering a timer and changing the colour with the span of time. Commercially used integrity indicators are Novas® Embedded Label developed by Insignia Technologies Ltd., Best-by™ from FreshPoint Lab and Timestrip® launched by Timestrip Ltd. (Insignia Technologies 2017; Freshpoint 2017a; Timestrip 2016). Zhai (2010) invented the “voice advertisement” intelligent packaging which carries a tiny battery, voice chip-integrated circuit, and loudspeaker. The music or vocal comments regarding product information/state was played on opening the package thus prohibiting forgery and modifying the purchase/dining experience of consumers.

Further, various gas indicators discussed above also work as integrity indicators because they may provide information about any leakage influencing the integrity.

Bioactive Packaging

Bioactive packaging may be defined as “a novel packaging technique where the bioactive/functional packaging materials hold the required bioactive compounds possessing functional properties at optimum level till they are emitted within the package throughout the storage or before consumption to improve the consumer’s health”. It is different from the active packaging techniques in the way that active packaging is mainly concerned with maintaining or enhancing the quality together with safety of food and beverage, whereas bioactive packaging makes the packaged foods healthier and thus is directly related to the consumer’s health. Several techniques which maintain the unique characteristics of biopolymers include microencapsulation, nanoencapsulation, enzyme encapsulation, and enzyme immobilization.

The bioactive packaging can be performed using the:

i. Regulated discharge of bioactive components from sustainable/biodegradable packaging systems
ii. Nano- and microencapsulation of bioactive agents in the packaging materials and also within food products
iii. Enzymatic activity to improve the health through transforming particular food-borne components (Lagaron 2005)

The biodegradable especially edible and sustainable matrices such as biomass-obtained thermoplastics, biodegradable polymers, emerging nano-biocomposites, polysaccharides and their derivatives, proteins and their derivatives, and smart biopolymers from microbes must be developed for the intact and prolonged shelf life integration and regulated release of bioactive compounds. Phytochemicals, vitamins, prebiotics, and nanofibers are the ideal functional components for integration in the package to promote the health. For the successful incorporation of bioactive substances, the following factors are necessary to obtain the required release rate as soon the package is opened and before its consumption:

i. Fabrication method of the films
ii. Optimal temperature/time combination for mixing bio-based packaging materials and functional substances
iii. Suitable packaging material
iv. Engineering mechanism

Encapsulation incorporates the enzymes, cells, food ingredients, or any other material in small capsules which protects them from moisture, cold/heat, or other adverse environmental situations increasing their stability and maintaining viability. Protein, fats, dextrins, starches, alginates, and various lipid compounds are used as encapsulating agents. The bioactive ingredients are released from the capsule using suitable methods like solvent activation which are site- and stage-specific and signalled using alteration in temperature, osmotic shock, irradiation, or pH (Lopez-Rubio et al. 2006). The application of enzymatic activity in transforming food is an emerging concept and is the most suitable and simple technique for enzyme immobilization is the encapsulation. The selection of suitable immobilization technique and biomaterial support to manufacture the enzymatic packages can be strongly based on the:

i. Characteristics of biocatalyst such as purified enzymes or whole cells derived from bacterial or fungal origin
ii. Expected storage constraints
iii. Kind of packed food
iv. Particular utilization of the biocatalyst

Nano-packaging

The nanotechnology, a science of tiny materials, is employed in food packaging to inhibit the food spoilage, maintain the quality, enhance the shelf life, and ensure the wholesomeness of food products and beverages. It may also assist the customers to improve the food as per their taste requirements and nutritional demands. A very minute amount of nanoparticle is enough to transform the packaging materials without significantly affecting their transparency, density, packaging, and processing properties because of a large aspect ratio of nanoparticle. Nanotechnology modifies the structure of any packaging material at molecular level.

Nanoscale-based innovation offers the novel modifications to food packaging by (i) improving barrier as well as mechanical properties, (ii) detecting the pathogens, and (iii) active/intelligent packaging thus exhibiting the food quality and safety advantages. The biodegradable films obtained from natural polymer have limited application in the packaging due to the inferior barrier and mechanical behaviour against the temperature control, carbon dioxide, oxygen, flavour and volatiles, moisture stability, and UV-blocking features as exhibited by the natural polymers, which can be improved using nanocomposites. Nanocomposites lower the packaging waste linked with processed products and preserve the fresh foods extending the shelf life. The packaging materials, bottles and other heavy packages by adding nanoparticles can be turned into lighter which possess resistance to fire and have stronger mechanical and thermal properties.

Nanocomposites

Most of nanocomposites are being developed for the beverage packaging due to their outstanding advantages over traditional packages. They modify the primary characteristics of packaging materials like strength, barrier properties, antimicrobial nature, and stability to heat/cold. Maximum work about the nanocomposites has focused to use montmorillonite clay (1–5% by weight) as a nanoscale component (must have one dimension <1 nm) in several polymers like polyethylene, polyvinyl chloride, nylon, and starch. Various methods like solution method, in situ, and melt processing method are employed to process nanocomposites. Nanocomposite plastic film and coating known as Durethan was produced by Bayer which is composed of clay nanoparticles spread uniformly across the plastic. Such nanoparticles block the path of moisture, oxygen, and carbon dioxide to make contact with content and thus prevent the diffusion process completely thus increasing the shelf life along with improving the quality (ETC Group 2004).

Beer can be now packed in plastic bottles using nanocomposites by Nanocor, subsidiary of Amcol International Corp, and have 6 months shelf life, earlier which was not possible due to flavour and oxidation problems. Research work has been undergoing to enhance the life of beer when packed in the plastic bottles containing nanocrystals up to 18 months by reducing the carbon dioxide loss from the bottle and restricting the oxygen entrance. Further, nanocomposite bottles are very light in weight thus lowering the distribution cost (ETC Group 2004).

Alternative Nanotechnology-Based Techniques

The carbon nanotubes are basically the cylinders containing the nanoscale diameters and used to improve the mechanical properties of package and also possess the antimicrobial activities. The cells of *E. coli* were punctured quickly on contact with the thin carbon nanotubes inducing the cellular injury (Kang et al. 2007a, b).

The nano-wheels developed by self-assembling of inorganic alumina platelets may be introduced into plastics to enhance their mechanical and barrier characteristics.

The food packages containing nanosensors detect the nutrient content of product as well as its quality. The nanosensors can find the toxins, chemicals, and microorganisms produced by the food. The biosensor made of poly (dimethylsiloxane) chips containing antibodies adhering to *Staphylococcus* enterotoxin B has an identification limit of 0.5 ng/mL. The nanovesicles can detect the pathogens like *L. monocytogenes*, *Salmonella* spp., and *E. coli* O157:H7. Moreover, the liposome nanovesicles may trace the peanut allergen proteins (Doyle 2006). NanoBioluminescence spray, with commercial name BioMark developed by AgroMicron, contained the luminescent protein that was adhered to the surface of microorganisms thus emitting visible glow varying in intensities based on the level of contamination (Joseph and Morrison 2006). Carbon nanotubes coated with DNA strands may be used to produce nanosensors to trace any odour and taste where the single DNA strand can be considered as a sensor and the carbon nanotube as a transmitter. Alike techniques are used in the synthesis of electronic tongue nanosensors to find out the compounds in parts per trillion thus warning the consumers on food spoilage. pSiNutria has developed nano-tracking technology which includes ingestible BioSilicon chip to monitor and detect the pathogens (Miller and Senjen 2008). Kraft had developed the nanosensors in association with Rutgers University that warns the consumer by colour change if food starts to spoil/degrade or has been fully spoiled using the electronic noses/tongues to taste or smell the flavours and scents (Sozer and Kokini 2009).

Nano-coatings are usually the waxy coatings employed for several products such as cheese, candies, chocolates, meats, fruits, vegetables, and bakery products which are strong barriers to the water vapour/moisture and gas. Recently, scientists have developed nanoscale edible film coating with a thickness of 5 nm which is not visible to the human eye. An edible antibacterial nanocoating was developed by the Sono-Tec Corporation, USA, which is useful for bakery products directly (El Amin 2007). Extensive research has been going on to develop nanoscale-based dirt-repellent coating.

Nanotechnology offers great advantages to the antimicrobial packaging by employing nanosilver which has antimicrobial activity at nanoscale and therefore can be incorporated in packaging polymers resulting in nanosilver composites for food preservation and extending the shelf life. Silver nanoparticles can reduce the 24 h bacterial growth to 98%. Nanocopper oxide, nanomagnesium oxide, and nano-titanium dioxide are also found to contain antimicrobial effects (Doyle 2006).

Responsive Packaging

Responsive packaging is the recent technology in packaging and can be defined as "the packaging system where package communicates due to the specific change in the package, food, headspace or external surrounding and emits encapsulated nutrients or active ingredients under specific environment to enhance the shelf life and quality of food, provide more convenience and theft resistance throughout the supply chain thus improving the packaged product safety". Responsive packaging system reacts only to stimulus present inside and outside of package where stimuli can be anything which adversely affects the food like food-borne threats, bacteria, moulds, contaminants, pH, moisture, or gas levels in the headspace. The direct contact between quality indicator/sensor and headspace or food product is necessary for providing the response about the food quality (Brockgreitens and Abbas 2016). Responsive materials such as self-assembled nanoparticles, hydrogels, layered films, supramolecular substances, and surface-grafted materials must be added into the packaging system which shows changes in chemical or physical characteristics in response to stimuli (Zelzer et al. 2013). The responsive food packaging can reduce the cases of food-borne diseases as seen in real time and also lower the food waste because fresh food is easily identified by consumers and processors (Gunders 2012). Responsive food packaging can be bioresponsive, chemoresponsive, thermoresponsive, and mechanoresponsive in nature based on the stimuli present in food or package.

No doubt, the responsive packaging is a kind of revolutionary technology for packing the food in the safest manner; however, various criteria must be taken into consideration before its commercialization. The performance of responsive materials must be clearly defined in terms of detection limit, sensitivity, working conditions, and range. They must exhibit reproducible response and should not display wrong indication of spoilage. This technology costs high, but its advantages in terms of improved safety and quality of food must be clearly presented to customers for satisfying them to paying extra money.

Microwavable Food Packaging

Microwave packaging aims at convenience and simply saves the time also. It also enhances the research and developments in novel microwavable food products. It regulates how uniformly and quickly a food heats. Moreover, the package may also provide the heated surface for creating high-heat steam environment for moisture retention, crisping, and browning (Regier et al. 2016). Earlier Al-foil-based containers were used widely, but many limitations like triggering microwave fires, arcing, magnetron destruction, and preventing microwaves penetration into food were observed. Susceptors are used as heating components which respond to the microwaves and thus regulate the heating rate to improve the cooking performance and prepare food like popcorn and frozen pizza crispy. Currently, the commercial susceptors are composed of metallized plastic films.

Recently, trays laminated using a polyester film of thin patterned aluminium were developed where patterned Al is employed to regulate and utilize the microwave energy. It distributes the microwave energy via specific Al patterning, transmitting it into frozen food to greater depth thus heating the food more uniformly and fast. Moreover microwave packaging employs strong sensors, digital displays, fuzzy logic, and other attributes improving the microwave cooking. The packages of the next generation communicate the consumer pr processor when you uncover, stir, add salt, etc.

Edible Packaging

Edible packaging makes it possible to eat food products on the retail counter along with their edible skins. It may reduce the food and packaging waste and migration of chemicals from the package to food. Edible packaging films and coatings are typically composed of proteins, carbohydrates, or fats based on their use. The substances for edible packaging must be considered like the additives when they have the edible purposes. Edible package must possess the necessary fundamental functional characteristics to act as a moisture barrier, and gases and novel blends or composites may be formulated for regulating the delivery of nutrients together with food additives (Campos et al. 2011). Currently, the edible packaging innovation lies in the following five categories in the food industry:

1. Food packed in an edible/biodegradable package
2. Food contained in food
3. A container or cup to be consumed with its beverage
4. Package that disappears
5. Edible packaging at quick-service restaurants

Edible packaging, one of the emerging technologies, supports the utilization of biodegradable polymers and sustainability and replaces the artificial compounds with natural ones. Further, it can be used as a medium delivery of functional or bioactive components, but diffusion of such compounds must be regulated. Further nanoscale structures may be incorporated in edible packages to enhance their applications; however full safety assessment is required before addition.

Recent Innovations in Packaging Materials

Glass containers are usually more resistant to several degradation factors in comparison to polythene and galvanized container. But the more oxidative stability is offered by brown container regarding physicochemical characteristics of the sunflower oil. The brown colour protects the contents from light which otherwise degrades the vitamins and pigments in the vegetable oils (Abdellah and Ken 2012).

The features of PET such as excellent clarity, UV resistance, mechanical properties, and good oxygen barrier characteristics make it the best choice in packaging of liquids that can be further enhanced using the several polymer layers to form multilayer PET. Oxygen scavengers may be incorporated in PET to reduce the level of oxygen in headspace and in the beverage and also reduce the oxygen ingress and increasing the shelf life (Bacigalupi et al. 2013).

Titanium dioxide (TiO_2) is often added to HDPE or PET containers to protect specialty drinks and milk against UV rays that are detrimental to their quality and also compromise recyclability. But it adds to the packaging costs. A novel oPTI process developed by Plastic Technologies Inc. results into a pure PET bottle that offers nearly 50% opacity due to the incorporation of foam without any additive addition and protects the products like drinkable yogurts, milk, and specialty milk products from the adverse effects of UV rays. The bottle is also recyclable and light weighted. Some other advancement in packaging materials includes:

1. Ready-to-use peel polymers which provide easy opening and resilience
2. Biodegradable Styrofoam derived from milk
3. Synthetic labelling adhesives meant for labelling of glass bottle

Recently, the emerging swing is to develop the new packaging materials with improved food-package-environment communication. Surface treatments for glass containers are necessary to improve the hydrolytic resistance of glass surface. In a study reported by Naknikham et al. (2014), glass was rinsed with many solutions like ammonium sulfate, alum, acetic acid, and citric acid, then cleaned and dried for

20 min at 110 °C. Glass treated with 5% alum showed the improved hydrolytic resistance.

Incorporation of nanoparticles in coating (Nanolok™ Technology) may enhance the oxygen barrier greater than four times than the PVDC-coated PET when RH varies from 0% to 80%. This coating will provide moisture barrier similar to PVDC-coated PET when examined at 85% RH and 40 °C. Such improvements in the barrier properties over a wide range of relative humidity are beneficial to enhance the flexible packaging performance to control the food quality and thus maintain the shelf life. R-Flute, the latest corrugated fluting, was developed by DS Smith Packaging that offers better surface for presentation and printing; Epotal Eco developed by BASF is the first of its kind compostable water-based adhesive that is certified by TÜV. Thus it offers the opportunities for developing multilayer films from biodegradable packaging materials which can be used as wrap for chocolate bar or potato chips.

Food Safety and Environmental Issues

The emerging innovations in packaging of food no doubt assure the quality of food products, but the safety of new techniques is still a great concern. This concern is due to the several problems especially faced during distribution of chilled food where a minute fluctuation in temperature may harm the food leading to spoilage. Nowadays temperature sensor embedded in RFID tags can be used along with their integration with physical and chemical sensors to provide traceability systems which is temperature maintained (Abad et al. 2009). The safety issues about the active and intelligent packaging may be considered because of the following factors:

1. The contents must be properly labelled to prevent the misuse by consumers.
2. The migration of active and intelligent compounds inside the food from package is also a big safety concern. Therefore, the active materials must be nontoxic in nature and comply with food regulations.
3. The working efficiency of active or intelligent packaging must preserve the food products without affecting their quality. They should provide reliable information about food spoilage or growth of microorganism in food matrices (Majid et al. 2016).

Surely nanotechnology has worked like a magical spell for food and beverage packaging industry; however its safety is still not sure. Nanoploymers when incorporated in suitable polymer may dramatically improve their characteristics. However, the additives with GRAS status must be evaluated once when employed at nanoscale to meet food safety regulations because the nanoparticles are more mobile, reactive, and toxic. Therefore the contents of nanoparticles must go through food safety assessment by suitable scientific association before their use in the beverage and food products as well as in packaging.

The environmental policies are necessary to meet the sustainable growth, but it puts extra cost during the food supply chain. Packaging materials are the main contributors to the solid waste stream. Therefore, the packaging industry is working hard to develop packaging materials with altered structure making them more eco-friendly and biodegradable (Bechini et al. 2008). One such material is polylactic acid which is composed of repeating lactic acid monomer; however it is still not widely used due to its high cost. Generally corn is employed as source material to prepare lactic acid required to be polymerized. Further soy based may be blended with polyester to invent novel packaging materials.

Future Trends

The manufacturers as well as processors must innovate the packaging more and more to retain the consumers worldwide. The food companies should make their customers brand loyal that is difficult to achieve due to the several unique choices consumer has. Digital printing can be seen as a good option for manufacturers to attach with consumers on a regional, individual, or emotional level. Active and intelligent packaging has no doubt several advantages than others, but scientists should also develop next-generation hybrid packaging providing environmental and functional benefits. The demand for biodegradable packages is on rise due to growing concern on sustainability which can be a strong purchase driver if price and quality for same product are similar. The packaging materials must be repurposable and reusable. There must be more versatility in pack sizes to meet the consumer requirements.

Conclusion

The rising consumers' demand for the natural, wholesome, and safe products has driven the packaging industry towards innovative packaging systems which can improve the safety and quality along with retaining the organoleptic attributes as well as the nutritional content of food and beverage and controlling the food-borne pathogens. Novel active/intelligent packaging materials are being developed to produce the sustainable, safe, and eco-friendly packaging solutions. However several safety issues such as degradation of the product quality and negative effects on human health must be resolved before their use. Further the twenty-first-century innovations are incomplete with nanotechnology which contributes greatly to improve the barrier and mechanical properties of container/package and design the amazing sensing technologies. The developments in biopolymer-based biodegradable packaging combining with nanotechnology result in reductions of wastage assuring the sustainability and also improve the package properties like never before.

Therefore, there must be complete understanding of working principles, mechanisms, and their optimal use to synthesize the packaging systems which would be efficient to maintain the food quality and safety. Currently, very less products are packed in new packaging systems in comparison to the number of research work carried till date. However, innovative technologies are expected to commercialize at a bigger platform in future. There is a strong need of collaboration of industry, prominent research institutions, and government agencies for the success of novel packaging techniques for food and beverage applications.

References

Abad E, Palacio F, Nuin M et al (2009) RFID smart tag for traceability and cold chain monitoring of foods: demonstration in an intercontinental fresh fish logistic chain. J Food Engg 93:394–399

Abdellah AM, Ken AI (2012) Effect of storage packaging on sunflower oil oxidative stability. Am J Food Technol 7:700–707

Ahvenainen R (2003) Active and intelligent packaging: an introduction. In: Ahvenainen R (ed) Novel food packaging techniques. Woodhead Publishing Ltd., Cambridge, UK, pp 5–21

Akbar A, Anal AK (2014) Zinc oxide nanoparticles loaded active packaging, a challenge study against *Salmonella typhimurium* and *Staphylococcus aureus* in ready-to-eat poultry meat. Food Control 38:88–95

Almenar E, Catala R, Hernandez-Munoz P, Gavara R (2009) Optimization of an active package for wild strawberries based on the release of 2-nonanone. LWT-Food Sci Technol 42:587–593

Anthierens T, Ragaert P, Verbrugghe S et al (2011) Use of endospore-forming bacteria as an active oxygen scavenger in plastic packagingmaterials. Innov Food Sci Emerg Technol 12(4):594–599

Bacigalupi C, Lemaistre MH, Boutroy N et al (2013) Changes in nutritional and sensory properties of orange juice packed in pet bottles: an experimental and modelling approach. Food Chem 141:3827–3836

Barbosa-Pereira L, Aurrekoetxea GP, Angulo I et al (2014) Development of new active packaging films coated with natural phenolic compounds to improve the oxidative stability of beef. Meat Sci 97(2):249–254

Basch C, Jagus R, Flores S (2013) Physical and antimicrobial properties of tapioca starch-HPMC edible films incorporated with nisin and/or potassium sorbate. Food Bioprocess Tech 6(9):2419–2428

Bechini A, Cimino M, Marcelloni F et al (2008) Patterns and technologies for enabling supply chain traceability through collaborative e-business. Inf Softw Technol 50:342–359

Blanco MM, Molina V, Sanchez M et al (2014) Active polymers containing *Lactobacillus curvatus* CRL705 bacteriocins: effectiveness assessment in Wieners. Int J Food Microbiol 178:7–12

Bodenhamer WT (2000) Method and apparatus for selective biological material detection. US patent 6, 051, 388 (Toxin Alert Inc. Canada)

Brockgreitens J, Abbas A (2016) Responsive food packaging: recent progress and technological prospects. Compr Rev Food Sci Food Saf 15:3–15

CAEN RFID (2017) CAEN RFID easy2log© RT0005. http://www.caenrfid.it/en/Caen Prod.jsp?mypage=3&parent=65&idmod=780 Accessed 14 May 2017

Calatayud M, López-de-Dicastillo C, López-Carballo G et al (2013) Active films based on cocoa extract with antioxidant, antimicrobial and biological applications. Food Chem 139:51–58

Camo J, Beltran JA, Roncales P (2008) Extension of the display life of lamb with an antioxidant active packaging. Meat Sci 80:1086–1091

Campos CA, Gerschenson LN, Flores SK (2011) Development of edible films and coatings with antimicrobial activity. Food Bioprocess Technol 4:849–875
Clariant (2017) Oxygen protection for packaged foods. http://www.clariant.com/oxy-guard-oxygen-scavenger Accessed 16 May 2017
Coma V (2008) Bioactive packaging technologies for extended shelf life of meat-based products. Meat Sci 78:90–103
CSL (2017) CS8304 cold chain temperature logging tag. http://www.convergence.com. hk/products/rfid/rfid-tags/cs8304/. Accessed 11 May 2017
Dainelli D, Gontard N, Spyropoulos D et al (2008) Active and intelligent food packaging: legal aspects and safety concerns. Trends Food Sci Technol 19:S103–S112 http:// dx.doi.org/10.1016/j.tifs.2008.09.011
Day BPF (2003) Active packaging. In: Coles R, McDowell D, Kirwan M (eds) Food packaging technologies. CRC Press, Boca Raton, pp 282–302
Day BPF (2008) Active packaging of food. In: Kerry J, Butler P (eds) Smart packaging technologies for fast moving consumer goods. Wiley, New York, pp 1–18
de Abreu PDA, Cruz JM, Losada PP (2012) Active and intelligent packaging for the food industry. Food Rev Int 28:146–187
de Abreu PDA, Losada PP, Maroto J et al (2011) Natural antioxidant active packaging film and its effect on lipid damage in frozen blue shark (*Prionace glauca*). Innov Food Sci Emerg Technol 12(1):50–55
De La Puerta MCCN, Gutierrez BC, Sanchez JC (2010) Smart packaging for detecting microorganisms. US Patent US8741596 B2, 21 Apr 2010
Doyle ME (2006) Nanotechnology: a brief literature review. Food Research Institute Briefings [Internet] https://fri.wisc.edu/files/Briefs_File/FRIBrief_Nanotech_Lit _Rev.pdf. Accessed 14 May 2017
EFSA (2014) Scientific opinion on the safety assessment of the active substances, palladium metal and hydrogen gas, for use in active food contact materials. EFSA J 12(2):3558–3566
El Amin A (2007) Nanoscale particles designed to block UV light. http://foodproductiondaily.com/news/ng.asp?id=80676 Accessed 18 May 2017
ETC Group (2004) ETC group report down on the farm: the impact of nano-scale technologies on food and agriculture http://www.nanowerk.com/nanotechnology/ reports/reportpdf/report10.pdf. Accessed 29 May 2017
Etienne M, Ifremer N (2005) SEAFOODplus-traceability-valid-methods for chemical quality assessment-Volatile amines as criteria for chemical quality assessment. http://archimer.ifremer.fr/doc/2005/rapport-6486.pdf. Accessed 13 May 2017
EU (2009) Guidance to the commission regulation (EC) No 450/2009 of 29 May 2009 on active and intelligent materials and articles intended to come into contact with food. Version 10. European Commission Health and Consumers Directorate- General Directorate E-Safety of the Food chain. E6- Innovation and sustainability
Ferrari MC, Carranzaa S, Bonnecazea RT et al (2009) Modeling of oxygen scavenging for improved barrier behavior: blend films. J Membr Sci 329:183–192
Ferrocinoa I, Greppia A, La Storiab A et al (2016) Impact of nisin-activated packaging on microbiota of beef burgers during storage. Appl Environ Microbiol 82:549–559
Freshpoint (2017a) BestBy. http://www.freshpoint-tti.com/time-from-opening-indicators/. Accessed 15 May 2017
Freshpoint (2017b) BestBy. http://www.freshpoint-tti.com/technology/. Accessed 15 May 2017
Georgescu I, Cobianu C, Dumitru VG (2008) Intelligent packaging method and system based on acoustic wave devices. US patent US 7755489 B2, 28 Apr 2008
Gontard N (2000) Panorama des emballages alimentaire actif (Panorama of active food packaging). In: Gontard N (ed) Les Emballages Actifs. Tech & Doc Editions, Londres. ISBN-10: 2743003871
Gunders D (2012) Wasted: how America is losing up to 40 percent of its food from farm to fork to landfill. NDRC Issue Paper IP:12–06-B https://www.nrdc.org/sites/default /files/wasted-food-IP.pdf. Accessed 6 May 2017

Hong SI, Park WS (2000) Use of color indicators as an active packaging system for evaluating kimchi fermentation. J Food Eng 46:67–72

Insignia Technologies (2017) Novas: embedded label. http://insignia.mtcserver11.com/ portfolio-view/novas-embedded-label/. Accessed 3 May 2017

Jamshidian M, Tehrany EA, Imran M et al (2012) Structural, mechanical and barrier properties of active PLA-antioxidant films. J Food Eng 110(3):380–389

Jayasena DD, Jo C (2013) Essential oils as potential antimicrobial agents in meat and meat products: a review. Trends Food Sci Technol 34:96–108

Jin T, Zhang H (2008) Biodegradable polylactic acid polymer with nisin for use in antimicrobial food packaging. J Food Sci 73:127–134

Jofré A, Aymerich T, Garriga M (2008) Assessment of the effectiveness of antimicrobial packaging combined with high pressure to control *Salmonella* sp. in cooked ham. Food Control 19(6):634–638

Johns Hopkins University Applied Physics Laboratory (2014) A colorimetric sensor of food spoilage based on a molecularly imprinted polymer. http://www.jhuapl.edu/ott/technologies/technology/articles/P01491.asp. Accessed 18 May 2017

Joseph T, Morrison M (2006) Nanotechnology in agriculture and food. A nanoforum report https://cordis.europa.eu/pub/nanotechnology/docs/nanotechnology_in_agriculture_and_food.pdf. Accessed 22 May 2016

Kang HJ, Jo C, Kwon JH et al (2007a) Effect of pectin-based edible coating containing green tea powder on the quality of irradiated pork patty. Food Control 18(5):430–435

Kang S, Pinault M, Pfefferle LD et al (2007b) Single-walled carbon nanotubes exhibit strong antimicrobial activity. Langmuir 23:8670–8673

Keep-it Technologies (2017) The shelf life indicator. http://keep-it.com/Accessed 2 May 2017

Kerry JP (2014) New packaging technologies, materials and formats for fast-moving consumer products. In: Han JH (ed) Innovations in food packaging, 2nd edn. Academic, San Diego, pp 549–584

Kerry JP, O'Grady MN, Hogan SA (2006) Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: a review. Meat Sci 74:113–130

Knee M (1990) Ethylene effects in controlled atmosphere storage of horticultural crops. In: Calderon M, Barkai-Golan R (eds) Food preservation by modified atmospheres. CRC Press, Boca Raton, pp 225–235

Laboratories STANDA (2017a) ATCO®. http://www.standa-fr.com/eng/laboratoiresstanda/ atco/. Accessed 4 May 2017

Laboratories STANDA (2017b) SANICO® is our range of antifungal coatings for the agro-food industry. http://www.standa-fr.com/eng/laboratoires-standa/sanico/Accessed 4 May 2017

Lagaron JM (2005) Bioactive packaging: a novel route to generate healthier foods. Paper presented at 2nd conference in food packaging interactions, Campdem (CCFRA), Chipping Campden, UK, 14–15 Jul 2005

Landau S (2007) The future of flavor and odor release. Paper presented at Intertech Pira conference on the future of caps and closures-latest innovations and new applications for caps and closures, Atlanta, 20–21 June 2007

Lawrie K, Mills A, Hazafy D (2013) Simple inkjet-printed, UV-activated oxygen indicator. Sens Actuators B Chem 176:1154–1159

Lee DS (2014) Antioxidant packaging system. In: Han JH (ed) Innovations in food packaging. Academic, San Diego, pp 111–131

Lee DS, Yam KL, Piergiovanni L (2008) Food packaging science and technology. CRC Press, New York, pp 243–274

LINPAC (2012) LINPAC packaging partners Addmaster to tackle packaging bugs. http://www.linpacpackaging.com/pt-pt/news/201208/linpac-packaging-partnersadd master-tackle-packaging-bugs. Accessed 21 May 2017

LINPAC (2017) Not just trays and film. https://www.linpacpackaging.com/en/not-just-trays-and-film. Accessed 15 May 2017

Liu XH, Xie SY, Zhou LB et al (2013) Preparation method of nano TiO_2 powder and method for preparing oxygen gas indicator from nano TiO_2 powder. China patent CN103641163A, 28 Nov 2013

Lloret E, Picouet P, Fernández A (2012) Matrix effects on the antimicrobial capacity of silver based nanocomposite absorbing materials. LWT Food Sci Technol 49:333–338

Lopez-Rubio A, Gavara R, Lagaron JM (2006) Bioactive packaging: turning foods into healthier foods through biomaterials. Trends Food Sci Technol 17:567–575

Lövenklev M, Artin I, Hagberg O et al (2004) Quantitative interaction effects of carbon dioxide, sodium chloride, and sodium nitrite on neurotoxin gene expression in nonproteolytic *Clostridium botulinum* type B. Appl Environ Microbiol 70:2928–2934

Majid I, Nayik GA, Dar SM et al (2016) Novel food packaging technologies: innovations and future prospective. J Saudi Soc Agric Sci https://doi.org/10.1016/j.jssas. 2016.11.003

Marcos B, Aymerich T, Monfort JM et al (2007) Use of antimicrobial biodegradable packaging to control *Listeria monocytogenes* during storage of cooked ham. Int J Food Microbiol 120:152–158

Marcos B, Aymerich T, Monfort JM et al (2008) High-pressure processing and antimicrobial biodegradable packaging to control *Listeria monocytogenes* during storage of cooked ham. Food Microbiol 25:177–182

Martínez-Olmos A, Fernández-Salmerón J, Lopez-Ruiz N et al (2013) Screen printed flexible radiofrequency identification tag for oxygen monitoring. Anal Chem 85:11098–11105

Maxwell Chase Technologies (2017) Fresh-R-Pax® trays. http://www.maxwellchase.com/food-packaging/absorbent-trays/. Accessed 4 May 2017

McAirlaid (2017) MeatPad. http://www.meatpads.info/en/Accessed 25 May 2017

Mennecke B, Townsend A (2005) Radio frequency identification tagging as a mechanism of creating a viable producer's brand in the cattle industry. Midwest Agribusiness Trade Research and Information Center, Iowa State University, Ames USA http://www.card.iastate.edu/products/publications/pdf/05mrp8.pdf. Accessed 1May 2017

Miller G, Senjen R (2008) Out of the laboratory and on to our plates – Nanotechnology in food and agriculture. http://libcloud.s3.amazonaws.com/93/b5/4/547/ Nanotechnology_in_food_and_agriculture_-_web_resolution.pdf. Accessed 7 May 2017

Mitsubishi Gas Chemical (2017a) AGELESS® http://www.mgc.co.jp/eng/products/abc/ageless/index.html. Accessed 15 May 2017

Mitsubishi Gas Chemical (2017b) AGELESS OMAC® oxygen absorbing film. http://ageless.mgc-a.com/product/ageless-omac/. Accessed 15 May 2017

NORDENIA (2011) Nor®Absorbit makes your food nice and crispy. http://www.worldpressonline.com/PressRelease/nordenia-innovative-packaging-for-microwave-dishes-31607.html. Accessed 12 May 2017

Naknikham U, Jitwatcharakomol T, Tapasa K et al (2014) The simple method for increasing chemical stability of glass bottles. Key Eng Mater 608:307–310

O'Grady MN, Kerry JP (2008) Smart packaging technology. In: Toldra F (ed) Meat biotechnology. Springer, New York, pp 425–451

Ozdemir M, Floros JD (2004) Active food packaging technologies. Crit Rev Food Sci Nutr 44:185–193. https://doi.org/10.1080/10408690490441578

Perry MR, Lentz RR (2009) Susceptors in microwave packaging. In: Lorence MW, Pesheck PS (eds) Development of packaging and products for use in microwave ovens. Woodhead Publishing Limited Cambridge, UK, pp 207–236

Pospiskova K, Safarik I, Sebela M et al (2012) Magnetic particles-based biosensor for biogenic amines using an optical oxygen sensor as a transducer. Microchim Acta 180:311–318

Realini CE, Marcos B (2014) Active and intelligent packaging systems for a modern society. Meat Sci 98(3):404–419

Regier M (2014) Microwavable food packaging. In: Han JH (ed) Innovations in food packaging, 2nd edn. Academic, San Diego, pp 495–514

Regier M, Knoerzer K, Schubert H (2016) The microwave processing of foods, 2nd edn. Woodhead Publishing Ltd, Cambridge, pp 273–299

Rooney ML (1995) Overview of active packaging. In: Rooney ML (ed) Active food packaging. Blackie Academic and Professional, Glasgow, pp 1–37
Salinas Y, Ros-Lis JV, Vivancos JL et al (2014) A novel colorimetric sensor array for monitoring fresh pork sausages spoilage. Food Control 35:166–176
Sealed Air (2017) Cryovac® OS films-rapid headspace. http://www.cryovac.com/NA/EN/pdf/osfilms.pdf. Accessed 10 May 2017
SEALPAC (2014) TenderPac-best meat quality, appetizing appearance. http://www.sealpac.de/fileadmin/user_upload/media/innovations/verpackungsloesungen/TenderPac_2014_online-EN.pdf. Accessed 17 May 2017
Sen L, Hyun KH, Kim JW et al (2013) The design of smart RFID system with gas sensor for meat freshness monitoring. Adv Sci Technol Lett 41:17–20
Sirane (2011) A-Crisp™ boxes, boards, sleeves and liners for crisping in a microwave. http://www.sirane.com/microwave-susceptors-crisp-it-range/sira-cook-crisp-it-susceptor-boards-boxes.html. Accessed 26 May 2017
Smith AJ, Poulston S, Rowsell L et al (2009) A new palladium-based ethylene scavenger to control ethylene-induced ripening of climacteric fruit. Platin Met Rev 53:112–122
Smolander M (2000) Freshness indicators for direct quality evaluation of packaged foods. Paper presented at International conference on active and intelligent packaging, Chipping Campden, UK 7–8 Sept 2000 pp 1–16
Sozer N, Kokini JL (2009) Nanotechnology and its applications in the food sector. Trends Biotechnol 27:82–89
Suppakul P, Miltz J, Sonneveld K et al (2003) Active packaging technologies with an emphasis on antimicrobial concise reviews in food science. J Food Sci 68:408–420
Tempra Technology™ (2017) Self chilling cans, Tempra Technology™ Florida, USA. http://www.tempratech.com/portfolio/i-c-cans/. Accessed 23 May 2017
Timestrip (2016) Timestrip® cold chain products for food. http://timestrip.com/products/food-range/. Accessed 15 May 2017
Uniform Code Council (2017) GS1 databar family. Available from: Lawrenceville NJ: Uniform Code Council https://www.gs1.org/barcodes/databar. Accessed 6 June 2017
Vermeiren L, Heirlings L, Devlieghere F et al (2003) Oxygen, ethylene and other scavengers. In: Ahvenainen R (ed) Novel food packaging techniques. CRC Press, USA, pp 5–49
VITSAB (2015) Seafood TTI labels. http://vitsab.com/?page_id=1983. Accessed 2 May 2017
Wanihsuksombat C, Hongtrakul V, Suppakul P (2010) Development and characterization of a prototype of a lactic acid–based time–temperature indicator for monitoring food product quality. J Food Engg 100:427–434
Yam KL, Takhistov PT, Miltz J (2005) Intelligent packaging: concepts and applications. J Food Sci 70:R1R10
Yeh JT, Cui L, Chang CJ et al (2008) Investigation of the oxygen depletion properties of novel oxygen-scavenging plastics. J Appl Polym Sci 110:1420–1434
Yoshida CMP, Maciel VBV, Mendonça MED (2014) Chitosan bio-based and intelligent films: Monitoring pH variations. Food Sci Technol-LEB 55:83–89
Zagory D (1995) Ethylene-removing packaging. In: Rooney ML (ed) Active food packaging. Blackie Academic and Professional, Glasgow, pp 38–54
Zelzer M, Todd SJ, Hirst AR et al (2013) Enzyme responsive materials: design strategies and future developments. Biomater Sci 1:11–39
Zenner BD, Benedict CS (2002) Polymer compositions containing oxygen scavenging compounds. US Patent, 6391406, 21 May 2002
Zhai RC (2010) Intelligent packaging bottle with voice advertisement. China patent CN201784843U, 22 Mar 2010