Film Based Packaging for Food Safety and Preservation: Issues and Perspectives

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Abstract

The extensive production of conventional plastics and their use in various food industries as packaging materials create a significant threat to the environment. This ends up creating problems concerned with performance, processing, and overall cost, thus being a big question in dealing with these non-renewable materials. The bioplastics evolved during development of renewable resources. As a part of the consequences to the dynamic changes in the present demand of customer and market scenario, the film-based active packaging system is of huge importance. The application of packaging systems is not to pose as a "wrap on," hence lowering the quality control. It should, anyway, serve as an "add on" for the protective measures taken to assure the safety and best quality of foods. This chapter aims to compile information on types of active food packaging systems, its commercial applications meant for improving food safety and quality with the extension of its life. It also describes various critical factors to be considered for commercialization, current market strategy, and legislative considerations, and application of bioplastic as packaging materials to meet ever-growing consumer demands with comparatively high quality fresh produce.

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15.1 Introduction

Microbial growth on food products leads to spoilage of many foods. During storage, the growth of undesirable microorganisms should be controlled either by coating antimicrobial substances on the food surface or incorporating these substances into food packaging materials. Employment of active packaging happens to be a new approach in food preservation, thereby enhancing the safety margin, reassuring the high quality of products, and incorporating antimicrobial agents in films based on polymers can be used as active packaging (Reyhan and Ozlem 2015; Ishrat et al. 2018). Antimicrobial packaging stands as one of the unconventional packaging concepts that tend to inhibit the growth of microorganisms on foods, maintaining its safety and freshness. Also, it is an alternative to non-thermal process that prevents the growth of heat-resistant microorganisms and their spores (Barbiroli et al. 2012; Hatice et al. 2019). On grounds of its potential to provide safety and quality benefits, film based antimicrobial packaging is drawing attention from researchers (Amin et al. 2018). Antimicrobial agents when incorporated into packaging materials inhibit the growth of microorganisms at the surface which is much prone to spoilage and contamination. This approach efficiently lowers the need for adding large quantities of antimicrobials into the bulk of foods (Koutsoumanis and Skandamis 2013).

Earlier researches suggest that a controlled release from the packaging film to the food surface is more advantageous over dipping and spraying (Buonocore et al. 2003; Broek et al. 2015). In this approach, natural or chemical antimicrobial agents incorporated into the packaging system/polymer ensure active packaging, thus limiting/preventing the growth of microbes by reducing their growth rate or extending their lag phase. Figure 15.1 illustrates seven types of antimicrobial food packaging system that are currently in vogue. Different types of ingredients along with polymeric materials are generally incorporated into the packaging system for development of biofilm based active packaging system. This extends shelf life besides improving the safety of the product. Due to the increase in demand for preservative-free products and less processed food, low levels of preservatives should be applied to packaging as they come in contact with food or other natural preservatives. Development of antimicrobial food packaging materials by incorporating natural antimicrobial agents into a polymeric material is a novel approach in food processing/packing industry. A thorough study of the existing works of literature specifies that natural antimicrobial agents such as spice volatile oils (black pepper, sage, thyme, rosemary, garlic, etc.), plant extracts (grape seed extract, olive leaf extract, etc.), organic acids, viz. citric acid, acetic acid, lactic acid, etc.), and bacteriocins (lysozyme, colicin, nisin, pediocin, etc.) are used to produce antimicrobial packaging materials (Fernandez-Pan et al. 2014; Marta et al. 2014; Rabin and Salam 2014).

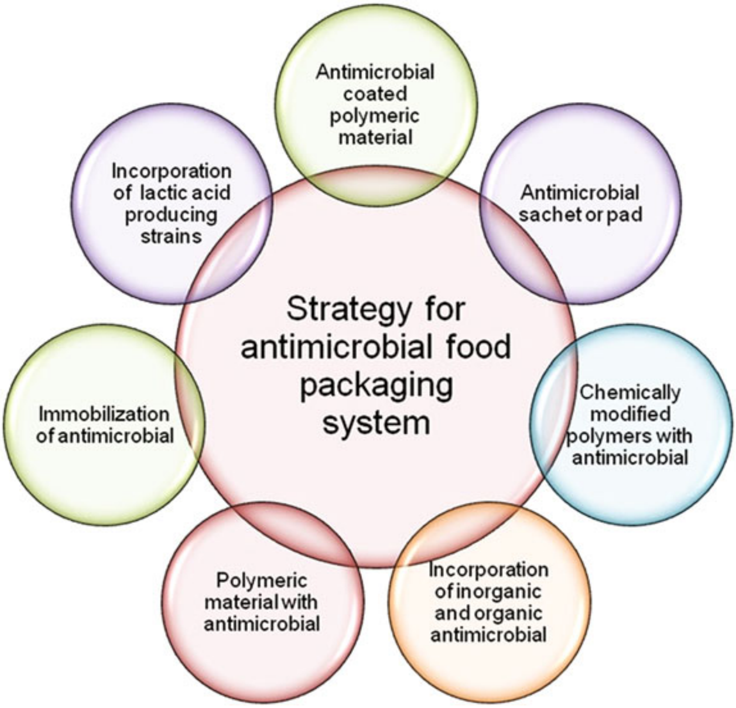

Fig. 15.1 Development of the antimicrobial food packaging system

15.2 Biodegradable Active Packaging System: Concepts and Commercial Applications

Chemically synthesized polymers have a greater demand as packaging materials on account of their low permeability values, excellent mechanical properties, and low cost. However safe environmental disposal of these materials is a major drawback. Environmental problems are due to non-renewable raw materials used for the development of the packaging system and subsequent accumulation of such non-biodegradable packaging elements in the environment. To overcome this challenge, research is focused on developing and manufacturing alternative packaging materials to chemical synthetics, considering the mechanical and permeability properties with economic feasibility. These biodegradable packaging materials that originate from completely renewable natural polymers have the ability to lessen environmental pollution and create space in the markets for agricultural products. But, incorporation of the antimicrobials into the packaging materials appends to the complications and manufacturing cost of the films. However, the costs of the film could anyway decrease in certain cases where replacement of expensive antimicrobials with the cheaper ones would still account to higher antimicrobial activity (Chana-Thaworn et al. 2011).

Presently, the production and marketing of eco-friendly cum biodegradable packaging materials have higher scopes in developing countries. However, in many cases the petroleum-derived polymers such as polystyrene and polyethylene still rule the packaging industry, posing severe threats to global concerns (Bitencourt et al. 2014). This leads to problems concerned with performance, processing, and costing, all of which are still big questions for these non-renewable materials. In this context, various types of materials used for packaging of food products have been reviewed earlier based on the biopolymer that includes both coatings, edible films along with packaging materials (Aloui et al. 2014). Tables 15.1 and 15.2 summarize reported examples of different types of biodegradable matrices with additives. Rationally, the use of either biodegradable and renewable materials composed of polysaccharides, proteins, lipids, polyesters or even a combination of all can turn out to be an effective solution to these problems.

In addition to that, some useful additives such as antioxidants, colorants, and antimicrobial agents can provide some functional properties to the packaging materials in order to inhibit or delay microbial or chemical spoilage of packaged food items.

15.2.1 Moisture Absorbers

Food products are required to control free water in order to enhance their shelf life. The presence of seeping liquids such as blood or other fluids in fish and meat products lessens the quality of the food items. An excess amount of water inside the packaged foods favors the growth of microbes, causing softening of food products like cookies and biscuit as well as hardening freeze-dried coffee and milk powder. On the other hand, excessive water loss may also promote the oxidation of fat. Thus, organic acids have been incorporated into the absorbent pads to inhibit the growth of microorganisms in these nutrient-rich foods. The entire mechanism is based upon the absorption process, which tends to either remove excess water or control the relative humidity in the headspace depending on the requirement. This demands the use of highly hygroscopic and dehydrating agents such as polypropylene glycol, cellulose fibers, carbohydrates, minerals, polyacrylate salts, molecular sieves, silica gel, and calcium oxide, etc. The size and weight of food, as well as the initial water activity of the absorber, absolutely determine the type of moisture absorber to be selected. Moreover, factors like humidity and temperature of the storage foods, the transmission of water vapor from the packaged foods, and sensitivity of food towards the moisture play essential roles (Liz et al. 2013).

Table 15.1 The reported examples of different types of biodegradable matrix with additives against some microorganisms

Types of biobased matrix	Antimicrobial agent	Target microorganisms	Reference
Hydroxypropyl methyl cellulose	Extract of kiam wood (*Cotyleobium lanceotatum*)	*S. aureus*, *L. monocytogenes*, and *E. coli* O175:H7	Aloui et al. (2014)
Gelatin from skin	Bergamot and lemongrass essential oils	*L. monocytogenes, E. coli, S. aureus*, and *S. Typhimurium*	Ahmad et al. (2012)
Whey protein	Lactic and propionic acids, chitooligosaccharides, and natamycin	*S.* aureus, *Y. lipolytica*, and *E. coli*	Ramos et al. (2012)
Wheat gluten	Potassium sorbate	*Fusarium incarnatum* and *Aspergillus niger*	Türe et al. (2012)
Soy protein	Nisin, EDTA, and grape seed extract	*L.* monocytogenes, S. *typhimurium*, and *E. coli* O175:H7	Sivarooban et al. (2008)
Carboxy methyl cellulose	Potassium sorbate	*Aspergillus parasiticus* and *Aspergillus flavus*	Sayanjali et al. (2011)
Fish skin gelatin and egg white	Clove essential oil	*E. faecium, V. parahaemolyticus, C. perfringens,* and *P. aeruginosa*	Giménez et al. (2012)
Triticale protein	Oregano essential oil	*S. aureus, P. aeruginosa*, and *E. coli*	Aguirre et al. (2013)
Sunflower protein	Clove essential oils	*Clostridium perfringens*, *E. faecium*, *B. coagulans*, *B. cereus*, *V. parahaemolyticus*, *P. fluorescens*, and *A. niger*	Sánchez-González et al. (2013)
Pea protein isolate, hydroxylpropyl methyl cellulose, methyl cellulose, or sodium caseinate	Bacteriocins	*L. innocua*	Beshkova and Frengova (2012)

15.2.2 Antimicrobial Packaging

During the manufacturing process, microbiological contaminations are likely to occur when inadequate food processing or under-processing occurs. However, some of these methods are not feasible in case of foodstuffs like fresh meat, fresh fish and seafood. Some of the agents like carbon dioxide, ethanol, antibiotics, chlorine dioxide, organic acids, essential oils, and spices, etc., having antimicrobial properties have been investigated to inhibit the growth of microbes that can deteriorate foodstuffs (Campillo et al. 2009). Packaging systems like essential oils, carbon

Table 15.2 Some reported biopolymer with natural antimicrobial additives used in the development of film based packaging system

Biopolymers		Antimicrobial agents	Type of food	References
Cellulose and derivatives	Cellulose	Pediocin	Meat	Rodriguez-Lafuente et al. (2010)
	HPMC	Ethanol/citric acid/ sorbic acid	Tomato	Rodriguez-Lafuente et al. (2010)
	Cellulose based paper	Nisin/Lacticin 3147	Cheese/ham	Johnson et al. (2018)
	Alginate	Nisin	Beef	Ishfaq et al. (2017)
		Nisin	MRS broth/ skim milk	Ferhat et al. (2017)
		Nisin	Poultry	Natrajan and Sheldon (2000)
	Chitosan	Sodium benzoate/ potassium sorbate	Culture media	Pastor et al. (2010)
		Acetic/propionic acid	Meat	Ouattara et al. (2000)
	Carrageenan	Chlortetracycline/ oxytetracycline	Poultry	Natrajan and Sheldon (2000)
Proteins	Wheat gluten	Sorbic acid	Ethanol-water	Lim et al. (2010)
	Corn zein	Lysozyme/nisin	Culture media	Gomez-Estaca et al. (2010)
	Soy protein	Lysozyme/nisin	Culture media	Padgett et al. (2000)
	Whey protein	Potassium sorbate	Water-glycerol	Ozdemir and Floros (2001)
		p-Aminobenzoic/ sorbic acids	Culture medium	Ozdemir and Floros (2001)
Polysaccharide	Starch and derivatives	Potassium sorbate	Straw berry	Perdones et al. (2012)

dioxide, plant extracts, allyl isothiocyanate also release volatile antimicrobials (Echegoyen and Nerín 2015). Chlorine dioxide existing in solid, liquid, gaseous has been proven to be effective for inhibiting the growth of various fungi, bacteria, and some viruses. It has potential applications in fish, poultry, meat, confectionery-baked foods, and dairy products (Yuyue et al. 2017). SO_2 has been used for controlling the decomposition of grapes, has better effects over the combination of gamma-radiation and heat treatment. The main drawback in case of SO_2 is bleaching grape-skin and that some of it may remain on the grapes (Yuyue et al. 2017). These residues leave a strong characteristic odor from the grapes that lead to product-rejection by consumers.CO_2 possesses a major role in the packaging atmosphere for inhibiting the growth of microorganisms and dropping the respiration rate of fruits and vegetables. CO_2 has to release continuously into the package for maintaining the favorable concentration in most packaging films. It was found that CO_2 has permeability between 3 and 5 times as that of oxygen. Meat products require high levels of CO_2 (10–80%) to suppress the microbial growth over the product-surface, thereby extending their shelf life (Zoran et al. 2015; Toorn et al. 2017). Carbon dioxide has advantages of acting on all the food inside the package without any contact with the food products and package whereas changes in the color of meat and blanching of vegetables are some of the disadvantages.

15.2.3 Carbon Dioxide Emitters

Sachets and absorbent pads are used as CO_2 emitters for preserving the muscle-based foods. The packaging of salmon (Marta et al. 2017) and cod fillets (Yingchun et al. 2016) has been tested with carbon dioxide emitters to obtain enhanced shelf life using vacuum packaging. CO_2 emitters lessen a headspace of packaging container by limiting the supply of gas to food products ratio compared to optimally modified atmosphere packages (MAP). This indicates improvement in the activity of MAP-system without compromising in quality and shelf life. In recent literature, applications of carbon dioxide emitters and MAP are found to extend the product-life by avoiding the collapse of packages (Holck et al. 2014). The market for CO_2 emitters is likely to grow and develop towards further development of films incorporating the functionality of CO_2 emitters (Day 2008). A recent application has been studied on the applications of the active packaging system for controlling the quality of meat products applied as ready-to-eat (Chen and Brody 2013).

15.2.4 Oxygen Scavengers

Several types of scavengers for O_2 molecules have been utilized for eliminating residual O_2. It can extend the shelf life of muscle-based foods. The most adaptable scavengers of O_2 are based upon the oxidation of iron powder. The organic-type scavengers like catechol, ascorbic acid, and polyunsaturated fatty acids have been thoroughly studied in place of metal-based scavengers that have been incorporated to polymer blends of packaging substrate (Lee and Ko 2014).

Oxygen scavengers with the inclusion of microbes were studied as an effective alternative for chemical scavengers, on being advantageous regarding consumer perception and sustainability. Recently, active packaging with enzyme embedded barrier coatings has been studied in food applications (Järnström et al. 2013). The developed active coatings were found to serve successfully to avoid the oxidation and rancidity reactions in packed foods stored in chilled conditions. Incorporation of functional groups, which is unsaturated in nature provides oxygen absorption capacity, can enhance the oxygen barrier behavior of polymer films (Nydia et al. 2017). UV light triggers the auto-oxidation reaction in the polymer with the help of a metal-based catalyst. Development of a system for oxygen scavenger with a natural free radical scavenger (for example, α-tocopherol) and a transition metal has done successfully (Kirschweng et al. 2017).

Another study indicated that nanoparticles loaded with α-tocopherol and iron chloride added to the gelatin films constituted the oxygen scavenging capacity (Byun et al. 2012). The inclusion complex showing stability in terms of its chemical-thermal stability is released. The nanocrystalline based on titania under UV radiation showed photocatalytic activity that has gained specific attention. An ascorbyl palmitate-β-cyclodextrin inclusion complex was found to be useful as an effective oxygen scavenger (Byun and Whiteside 2012). Titania nanoparticles were added to different polymers to successfully develop oxygen scavenger films (Jong-Whan et al. 2013). Organic substances can be oxidized O_2 consumption and CO_2 production due to the light-induced catalytic activity of nanocrystalline based on TiO_2 on the polymer surfaces. Photocatalytic titanium films have potential as antimicrobial packaging system as they are known for microbes-inactivation (Lee and Ko 2014).

15.2.5 Antioxidant Packaging

Fat oxidation is one of the vital processes responsible for food spoilage due to microbial growth. On the other hand, lipids oxidation in foods reduces their shelf life because of variations in taste and aroma. It also reduces the functionality, textures, and nutritional quality of the muscle foods and reduces the nutritional quality of the food products (Pereira de et al. 2010; Busolo and Lagaron 2012).

The application of oxygen scavengers and antioxidants packaging material can prevent the oxidation of food. The oxidation process which affects the food quality is thereby prevented or slowed down with such a packaging (Joaquín et al. 2014). Natural oxidants like Vitamin E and the extract rich in phenolic compounds (clove, oregano, cinnamon, ginger, etc.) are the additives that are gathering regard (Jeannine et al. 2018). Antimicrobial and antioxidant properties are exhibited by spices containing phenolic groups like flavonoids and various phenolic acids (Maria and Jose 2012). Yet, the major initiators of oxidation are the radicals (mainly hydroxyl, oxo, and superoxide) produced through the oxidation process. Rapid elimination of radicals on their formation itself can, therefore, prevent oxidation. Further oxidation is also prevented by some natural compounds that trap the radicals and react efficiently with them. The sole presence of a radical scavenger is far effective over high barrier or vacuum packaging materials to protect food against oxidation in such a case. The stability of myoglobin and the fresh meat against oxidation can be improved by the application of antioxidant-based active film used in the preservation of fresh meat (Silvia et al. 2017). An increase in fresh odor and improved oxidative stability has been observed in lamb steaks using an active film based on rosemary and oregano (Yingchun et al. 2016). Lipid oxidation in milk powder can be delayed through α-tocopherol migration from an active packaging film (fabricated with the high-density polyethylene, ethylene vinyl alcohol, and α-tocopherol) (Silvia et al. 2017). Apple slices have been covered with cellulosic films incorporated with cysteine and sulfite to obtain brighter apples with less browning (Magnea et al.

2014). Diffusion and evaporation of antioxidant substrate from the surface of the film lead to decreasing its contents during storage through the film. Addition of an extra layer of the film having low permeability to antioxidants (Elahe et al. 2018) or the use of cyclodextrins (Atul et al. 2017) can prevent this decrease in the concentration of antioxidants applied for fresh meat, nuts, butter, oil, fruits bakery products.

15.2.6 Bioactive Edible Packaging Films

Recent days extensive research works have been conducted to develop biodegradable and edible packaging material from natural polymers to avoid the problems caused by the synthetic plastics. These biodegradable packaging materials can remediate the environmental problems and growing health concerns. Basically, these kinds of films are prepared from fruits extracts, juice, pulp, and vegetable purees due to its edible property, easy collection, and facile processing. Utilization of agriculture by-products like fruit peels and vegetable skins has drawn the attention of the researchers to prepare this edible film, and this can address the sustainability of environment and resource re-cycling process. The phenolic compounds obtained from the phytochemicals play a major role as the additives in the edible package. These can even improve the functional and physical properties of the film through cross-linking within the protein or polysaccharides based (Nie et al. 2015).

The tea polyphenol was used as natural antimicrobial agents in various food industries considering its biocompatibility, nontoxic, and low cost by some researchers (Shao et al. 2018). The edible packaging film was developed by incorporating the active ingredients of tea polyphenol into protein, polysaccharides, gelatin, and starch, etc. (Li et al. 2012; Liu et al. 2015; Dou et al. 2018). The shelf life and quality of oil was maintained by developing the active film made from gelatin and impregnated with tea polyphenol by retarding the lipid oxidation (Volpe et al. 2017).

15.3 Factors to Be Considered for Commercialization of the Active Packaging System

While designing and modeling antimicrobial film or packaging system for food preservation, there are several factors to be taken into consideration. Also, the choice of each substrate in conjunction with antimicrobial substance plays a vital role in the development of antimicrobial packaging system. With varying types of foods and nature of the antimicrobial components, physico-mechanical activities of package might change accordingly. Various factors responsible for development of active packaging system have been illustrated in Fig. 15.2.

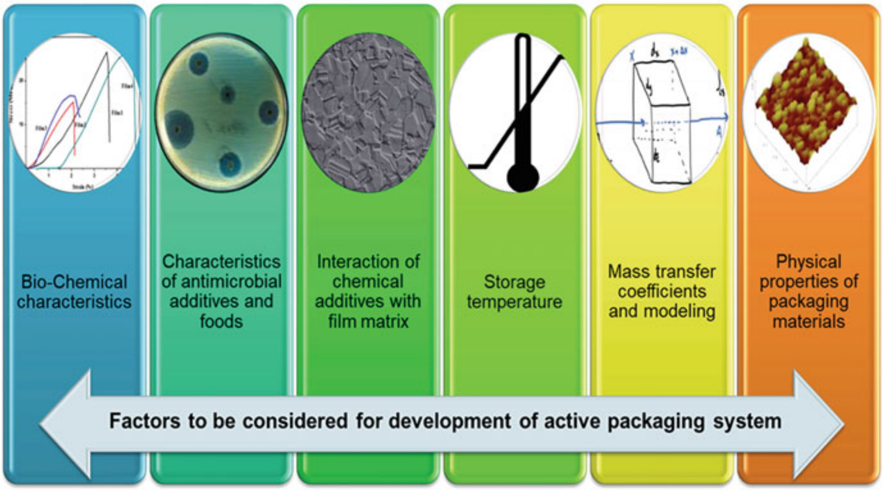

Fig. 15.2 Various factors responsible for development of active packaging system

15.3.1 Biochemical Characteristics of Films

As per earlier studies, the potency of an incorporated antimicrobial agent might sink throughout film fabrication, distribution, and storage (Mila and Carmen 2013). The cutting pressures and forces within the processing conditions in addition to the heat labile nature of element throughout extrusion boldly restrict the selection of antimicrobial (Agustín and Cecilia 2013). A mixture of low-density polyethylene (LDPE) resin and potassium sorbate powder help in the synthesis of a master batch. The heat decomposition of these pellets may be inhibited by the addition of LDPE resin (Amalini et al. 2018). Additionally, quantitative characterization of all other operations like lamination and drying in with the adhesive chemicals ought to be done. In some cases, during storage a good number of the volatile antimicrobial compounds could also be lost. Most of these parameters must be assessed.

15.3.2 Characteristics of Antimicrobial Substances and Foods

The effectiveness of antimicrobial substances and their release is considerably affected by food elements. The growth of microbes can be mathematically modeled by a typical study on the mechanism and dynamics of growth inhibition. Possibilities of alteration of the activity of antimicrobial substances by the physicochemical characteristics of the food cannot be eliminated. It is quite familiar that the growth rate of target microbes and the degree of ionization of the prime active chemicals are greatly affected by the pH of a product (Amalini et al. 2018). For example, polyethylene film containing carboxylic acid compound was reported to have more ability to inhibit molds at low pH levels. Indefinite quantity of oxygen will be exploited by the aerobic microorganisms for their growth. The water activity of food can further influence the antimicrobial activity and chemical stability of incorporated active compounds considering the fact of every food having its own microflora. The rate of diffusion of potassium sorbate in MC/HPMC film containing saturated fatty acids was found to be high at higher values of free water. With respect to the contaminating microbe, designing of the release kinetics of antimicrobial agents should be done in a way that keeps up the concentration on top of the essential inhibitory concentration (Phakawat et al. 2015).

15.3.3 Interactions of Chemical Additives with Film Matrix

The polarity and mass of additive has to be considered necessarily during incorporation of additives into a polymer. Additives with high molecular weight and low polarity have extra compatibility with the non-polar LDPE. The diffusion rates of different additives within the polymer depend upon their ionic charge, molecular weight, and solubility. Recently, the diffusion of antioxidant, sodium ascorbate, and potassium sorbate in calcium-alginate films at 8 °C, 15 °C, and 23 °C was analyzed and experimented by some researchers. They found that antioxidant activity is the highest with sodium ascorbate and lowest diffusion rates at all the studied temperatures (Phakawat et al. 2015).

15.3.4 Storage Temperature

The antimicrobial activity of chemical preservatives may also be affected by the storage temperature. Usually, increase in storage temperature will result in high diffusion rates within the polymer leading to acceleration of active agent's migration within the film and deterioration of protective action of antimicrobial films (Elahe et al. 2018). The impact of temperature conditions on the antimicrobial activity of active compounds, their rate of diffusion, and the concentration within the film throughout production should be predicted in a way that sufficient temperature is maintained effectively throughout the product's life (Volpe et al. 2017). Few demonstrations by certain researchers state that low-density polyethylene (LDPE) containing low amounts of carboxylic acid anhydrides can be effective both at very low and high temperature (Kenneth 2017).

15.3.5 Mass Transfer Coefficients

Diffusion stands to be the most elementary system in facilitating release of active ingredient from packaging material into the food system. The advantages of using a multilayer packaging are that the antimicrobials are present in an additional skinny layer, their migration and release being controlled by the film density. It is also very important to manage the rate of migration of active substances from the food package. The migration of active substances through the packaging systems composed of multi layers and can be described by a mass transfer model. The diffusion method may enable prediction of the release profile of antimicrobial agent and so the time through which the agent remains higher than the essential effectiveness concentration, by means of mathematical modeling. A semi-infinite model with a larger volume of food component, consisting of packaging element having a finite thickness which leads to infinite volume of the food element might be practical as compared to the packaging material (Lecoq et al. 2016; Ye 2016). The boundary conditions to be employed in mass transfer modeling are identifiable.

15.3.6 Physical Properties of Packaging Materials

The physical properties, processing, or mechanical aspects of the packaging material might be affected by the antimicrobial agents. On addition of the active agents to the heterogenous formulations, the performance of the packaging materials has to be retained (Jian-Hua et al. 2014). It was found in some studies that even on enhancing the concentration of benzoic anhydride from 0.5% to 1.0%, no variations in opacity and strength of LDPE film could be observed (Dobias et al. 2000). There were reports of similar results on plant extracts like propolis and clove. LDPE film coated with MC/HPMC exhibited a negative effect on the heat-seal efficiency due to the presence of nisin in it (Xiaowei et al. 2012).

15.4 Technological Applications in Active Food Packaging System

15.4.1 Application of Antioxidant Agent with Edible Films for Fruits and Vegetable Preservation

Various commercial applications of antioxidant-based packaging system for fruits and vegetables have been summarized in Table 15.3.

15.4.2 Application of Antioxidant Agent with Edible Films for Meat and Fish Preservation

Freshly caught fish spoils very quickly. With time spoilage rate accelerates. Practicing hygienic slaughter and handling of carcass help improve shelf life. Significant amount of spoilage in fish and meat is caused by bacteria. Autolytic spoilage due to fat oxidation and enzymes is also observed. Generally, tinned steel is used to store fish and meat products. Currently, antioxidant-based packaging materials are being used to preserve the products. Various commercial applications of antioxidant-based packaging system for fish and meat products have been summarized in Table 15.4.

Table 15.3 Antioxidant agent with edible films for fruits and vegetable preservation for commercial applications

Film or coating	Antioxidant compound	Application	Analyses	References
Chitosan coatings	Garlic, cranberry, carvacrol rosemary, onion	Squash butternut	Polyphenol oxidase and peroxidase activities	Volpe et al. (2017)
Whey protein concentrate and beeswax	Ascorbic acid, cysteine, and 4-hexylresorcinol (4-hexyl)	Apple	Weight loss, color, sensory evaluation	Kenneth (2017)
Methylcellulose polyethylene glycol and stearic acid in 3.0 g:1 mL ratio	Ascorbic acid, citric acid	Apricots and green peppers	Water loss, vitamin C	Lecoq etal. (2016)
Gellan and alginate with glycerol	Ascorbic acid	Papaya	Respiration rate, water loss, firmness, content of ascorbic acid, and production of ethylene	Jian-Hua et al. (2014), Ye (2016)

Table 15.4 Antioxidant agent with edible films for meat and fish preservation for commercial applications

Polymeric materials	Antioxidant compound	Application	Analyses	Reference
Milk protein-based film	Oregano and/or pimento essential oils	Beef muscle	TBA	Kenneth (2017)
Gelatin-based films with chitosan	Rosemary or oregano essential oils	Cold-smoked sardine	TBA, total phenol, FRAP method	Dobias et al. (2000)
Soy protein	Ferulic acid	Lard	PV	Garcia et al. (2004)
Alginate and glycerol coating	Sodium ascorbate and citric acid	Buffalo meat patties	TBA, tyrosine value, sensory quality	Ayranci and Tunc (2004)
Chitosan coatings	Fish oil, vitamin E	Lingcod fillets	TBA	Lecoq et al. (2016)

15.4.3 Polymer Nanotechnology in Packaging

Over 30,000 various natural and synthetic polymers are known today and it is important to understand their effects on human health before utilizing them as packaging systems. Bio-nanofibers such as chitosan, cellulose, and collagen have superior properties compared to traditional polymers—high specific surface area per unit of weight, excellent mechanical properties, and are light. These properties make them ideal, either as packaging materials or as additives to be integrated into polymer matrix by injection to improve function (Zhongxiang et al. 2017). New innovations in nanotechnology for food preservation include active packaging involving the combination of antimicrobial substances with food packaging materials. This majorly includes incorporation of antibacterial nanoparticles into polymer films. It was observed that an intensive contact between food product and packaging material is necessary in the case of both migrating and non-migrating antimicrobial materials. Hence potential food applications include vacuum or skin-packaged products, e.g. vacuum-packaged meat, fish, poultry, or cheese. Nanocomposite materials reportedly show greater barrier properties, mechanical strength, and temperature resistance as opposed to traditional composites. Fillers like nanoclays, carbon nanotubes, kaolinite, and graphene nanosheets boost shelf life by acting against the diffusion of gases and flavor-giving volatiles (Attrey 2017; Elisa et al. 2018). Among the materials that received considerable attention for their sustainability are cellulose and polylactic acid (PLA) because they are biodegradable materials with suitable mechanical and optical properties. PLA, additionally, offers the advantages of easy production (its monomer lactic acid is a fermentation product of carbonaceous feedstock) and biocompatible disposal compared to traditional petro-based polymers. It is also possible to integrate antimicrobials with carriers like plastics, paper-based materials, textile fibrils, and packaging materials. Fluorescent nanoparticles integrated with antibodies help in identifying chemical and food borne pathogens. In order to successfully employ polymer nanotechnology in food technology it is important to consider the complete lifecycle of the material which helps in understanding its holistic impact in all stages of production and on all forms of life and environment. Life cycle assessment (LCA) studies help in monitoring the said impacts right from raw materials in production to usage until disposal. They also help in optimizing material and energy recovery for sustainability.

15.5 Recent Patents for Active Packaging System

For search of information related to active food packaging system, different web-resources have been used, such as Google patents, The Web of Knowledge, and WIPO (World Intellectual Property Organization). In order to analyze the application of active packaging in food with respect to issued patents, number of patents evolved from January 2009 to April 2019 was retrieved from the PATENTSCOPE database under WIPO. The search was performed using “FP:(Active Packaging of food)” as a keyword. Six hundred and sixty-one number of the patents on the application of active packaging in food were published in the last 10 years. For all the obtained data, various aspects like: title, abstract, assignee country, number and date of deposit, etc., were analyzed. It was found that, China has contributed maximum number of patents (227) in this field followed by Russian Federation (114) till date as shown in Fig. 15.3.

The number of applications increased in 2012, peaking in 2017, signaling a potential increase in product and process innovation in a global context. After 2017, there is a slight decrease and constancy was observed in the following years. 2017 was the year with the highest number of patents granted (Fig. 15.4).

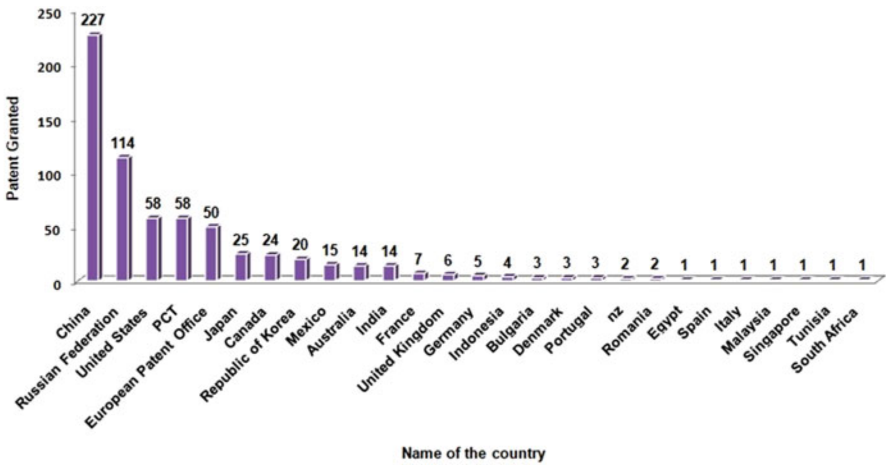

Fig. 15.3 Patents granted worldwide in the topic of active packaging system of food obtained from the PATENTSCOPE database under WIPO as on year 2019 (Source of Data: https://patentscope.wipo.int/search/en/result.jsf)

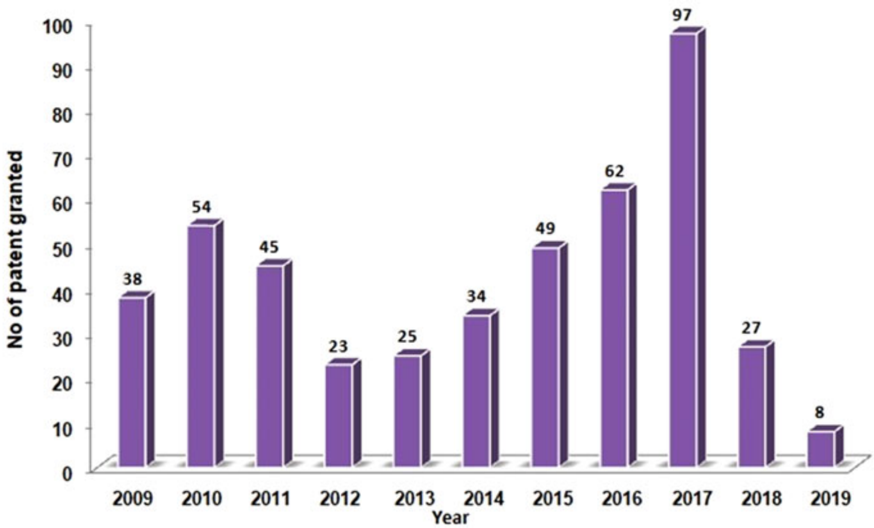

Fig. 15.4 Year wise patent granted in the area of active food packaging system obtained from the PATENTSCOPE database under WIPO as on year 2019 (Source of Data: https://patentscope.wipo.int/search/en/result.jsf)

Active food packaging technologies are evidently growing in size, to extent that they are best described as an "emerging technology." It was found by the key IPC (International Patent Classification) class level for the largest technology groups. The IPC A23L contributes maximum, i.e. 32%, which denotes human necessities

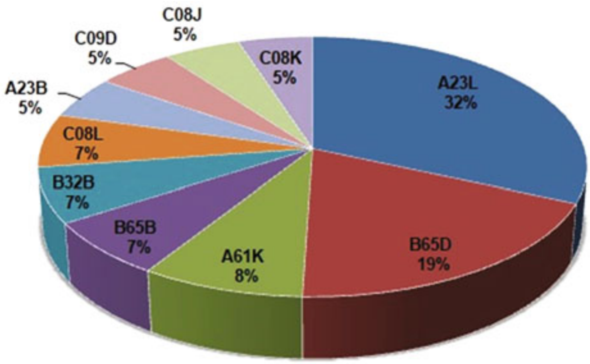

Fig. 15.5 Active packaging system with respect to IPC (International Patent Classification) contribution obtained from the PATENTSCOPE database under WIPO as on year 2019 (Source of Data: https://patentscope.wipo.int/search/en/result.jsf)

(Food, food stuffs, and non-alcoholic beverages). IPC B65D contributes 18%, denotes performing operations, (Containers for Storage or Transport of Articles or Materials). Development of food packaging bags, barrels, bottles, boxes, cans, cartons. The IPC C08L contributes 7%, applicable for organic macromolecular compounds and their preparation or chemical working-up in the development of active packaging (Fig. 15.5).

15.6 Intelligent Packaging System

15.6.1 Radio Frequency Identification (RFID) System

RFID technology cannot be classified either as a sensor or indicator whereas it constitutes a separate information-based electronic device to form an intelligent package device. RFID transmits accurate and real-time information using tags attached to assets (containers, pallets, cattle, etc.). It is an automatic identification system with a group including bar-codes. Hence, it is offering a number of probable aids in meat production and distribution. This aid comprises inventory management, traceability, security, and safety (Min and Peichong 2012). RFID technology also plays a major role in prevention of product recalls (Nora et al. 2012). Though the application of RFID technology to packaging is quite a latest development, it has been accessible for about 40 years (Lindsey et al. 2014). Shipping to suppliers, receipt by distribution centers (DCs), and put-away processes with retailers can be improved through the access of RFID technology in retail industry (Fabien et al. 2017). There have been reports regarding a fruit warehouse employing the RFID-based traceability system (Lindsey and Ning 2013). In addition to that, RFID technology was applied to the British livestock industry to explore the significance of the traceability system as well as closely study its potential costs and utility (Yong-Shin et al. 2012). Apart from these, improvement in replenishment productivity and reduction of stock loss in the supply chain of short shelf life products can be achieved by adopting RFID technology. RFID technology is accessible through the complete supply chain for retail-foods industry which consists of tighter management, control of the supply chain, reduced shrinkage and labor costs, improved customer service, and compliance with traceability protocols and food safety regulations (Rahul et al. 2017).

15.6.2 Time–Temperature Indication System

Time and Temperature Indicators (TTIs) on account of their simplicity, affordability, low cost, and efficiency have been largely utilized (Zabala et al. 2015). Development of various TTI trade has occurred on the enzymatic base and both polymeric and biological reactions. Kinetic study with modeling of loss ratios, food quality and response poses as a prerequisite for the productive implementation of a control system based TTI (Tsironi et al. 2011). It is essential to track the changes in parameters like time and temperature from production to consumer in order to ensure the quality and safety of food products that require optimal temperature (Wu et al. 2015). TTI can be stored in the form of a small sticker, in transport or individual containers. The exposure of food to a different recommended temperature will reflect an irreversible chemical change. In cases where cold storage is a critical control point during transport and distribution, TTI delivers vital contributions for the safety and quality of chilled/frozen food (Kuswandi et al. 2012). TTI indicates of products being heated above or cooled below a critical temperature, thus warning the consumers about the chances of the survival of pathogenic microbes and protein denaturation processes. The pasteurization and sterilization processes can be analyzed by application of TTIs (Kim et al. 2013, 2016). A collective indication of the storage temperature to which the TTI is exposed, is given by the visible response. Depending on their response mechanism, partial history or full history indicators are the classifications of TTI. There is no response by partial history indicators until a temperature threshold has been exceeded, indicating the exposure of a product to a temperature that is sufficient to change its quality or safety. A continuous temperature-dependent response is given by Full history TTIs throughout the history of a product, thus constituting the prime focus of interest for research and commercial use (Chun et al. 2017). The chemical, enzymatic, or microbiological changes initiated by the response ought to be visible, irreversible, and temperature-dependent (Eun-Jung et al. 2014).

15.6.3 Gas Indication System

The activity of the food product, nature of the package, environmental conditions lead to changes in the gas composition in the package headspace. O_2 and CO_2 are utilized for monitoring the food quality, and as seal indicators (Chompoonoot et al. 2014; Tumwesigye et al. 2017). A change in the color is also detected due to chemical or enzymatic reactions occurred by O_2 or CO_2 indicators. A color change is indicated, if the concentration of the O_2 exceeds a predefined limit in a sealed food package. Redox dyes such as methylene blue, 2,6-dichoroindophenol, and N,N,N′, N′-tetramethyl-p-phenylenediamine are used as O_2 indicators (Lina et al. 2017). Similarly changes in color also occurred when CO_2 concentration decreases to a specific level. It has found that visual indication for release of CO_2 is formed by calcium hydroxide. Indicator of CO_2 is caused by calcium hydroxide. The O_2 sense is an indicator for the products packed in modified atmosphere packaging (MAP) (Alessia et al. 2013; Chau and Keehoon 2013). However, such type of indictor requires anaerobic condition to be maintained as it deteriorates quickly in the presence of air. The application of indicator which changes its color in the presence of oxygen is one of the novel approaches. In some cases, the indicator has to be activated with UV light (Pradeep et al. 2012).

15.6.4 Pathogen Indication System

Detecting the presence of harmful microorganisms in food is a novel way to identify contamination before consumption. Food Sentinel System™ and Toxin Guard™ are the commercially available visual indicator system used in the packaged food. Here, food must not be consumed if the color has changed. The Food Sentinel System™ is a visual system that chromogenically indicates contamination in food packages. The underlying mechanism is that it detects the presence of harmful microorganisms through immune reactions that make the barcode unreadable. In many cases, an antibody specific pathogen (*Escherichia coli* 0157:H7, *Listeria monocytogenes*, *Salmonella*) is made fixed to a membrane that gives rise to a product of the barcode (Goldsmith et al. 1999). Another commercial indicator known as Toxin Guard™, which is used to detect the freshness and biochemical characteristic through the incorporation of monoclonal antibody in a polymeric base. It can detect other pathogens such as *Campylobacter* sp., *Salmonella* sp., and *Listeria* sp., *Escherichia coli*. Moreover, it can detect the metabolites produced through the bacterial degradation of the food product (Goldsmith et al. 1999).

15.7 Market and Legislative Considerations for Packaging System

Packaging sector is a diverse industry with each of its sectors having significant impact on global markets. There is a growing interest in consuming fresh products with extended shelf life and controlled quality and hence it is upon the manufacturers to provide safe packaging. This is the main challenge as well as the driving force to develop improved strategies and technology (Aaron and Erik 2017; Kalliopi et al. 2018). Packaging materials that serve as an adequate barrier to gases, UV protection, and extension of the storage period, transparency, and environmental performance are hence under great demand and are reportedly the future of food packaging (Farmer 2013; Lindh et al. 2016). This is supported by the fact that advanced packaging represents about 5% of the total value of the packaging market, of which 35% belongs to active systems. There are indications that soon there would be a further increase in these numbers in the coming years, both in their market share as well as their patent grants.

Though the origin of such solutions was in Japan and the USA initially, they have now crept into the formerly restrictive Europe (Ghaani et al. 2016). The latter further indicates the growth in research interest in those particular problems in their markets (Lee et al. 2015). These trends also suggest that active materials must be brought to the market after proper and effective application and after their screening for meeting legislative requirements. The changes that these materials may undergo with time when in contact with food must also be considered (Realini and Marcos 2014).

15.8 Bioplastic: The Upcoming Food Packaging Material

The synthetic plastic used in the food packaged materials creates major problems like toxicity, decomposition, and its accumulation in the environment. In some cases, it induces the ecological impact very badly in case of landfills and also causes water contamination. The solution to avoid these problems associated with synthetic plastic would be the replacement of synthetic polymers by biodegradable polymers. The bioplastic can be prepared on the basis of three combinations as follows:

- Petroleum-based bioplastic: These are synthesized from petroleum resources. However, these are found to be biodegradable by nature at the end of their functionality.
- Mixed source-based (bio- and petro-) bioplastic: These are synthesized and developed with a combination of biobased and petroleum monomers.
- Renewable resource-based bioplastic: These are either synthesized naturally from plants and animals, or from renewable resources.

Various categories of bioplastics have been illustrated in Fig. 15.6. In the present days, bioplastic production contributes only one percent of 320 million tonnes of plastic production annually. As per the report given by European Bioplastics, global bioplastic production will be increased to 2.44 million tonnes in the year 2022 based upon the demand and revolution for environmental sustainability (Rukhsana et al. 2019).

Bioplastic based food packaging system and its commercial applications have been summarized in Table 15.5.

It was concluded that, PLA (polylactide) is mostly used in the market out of various biobased materials commercially. However, main applications for bioplastics are used for short shelf life products. Several researches on PLA based packaging proved that they could replace the conventional packaging system. In one study, the comparison of whole green peppers packed in a PLA based film and LDPE (low-density polyethylene) was investigated. There was no significant difference in color, hardness, and ascorbic acid concentration was observed (Koide and Shi 2007). It was also reported that PLA packaging is suitable for storage of fresh orange juice at 4 °C for 14 days. Moreover, the color changes, ascorbic acid

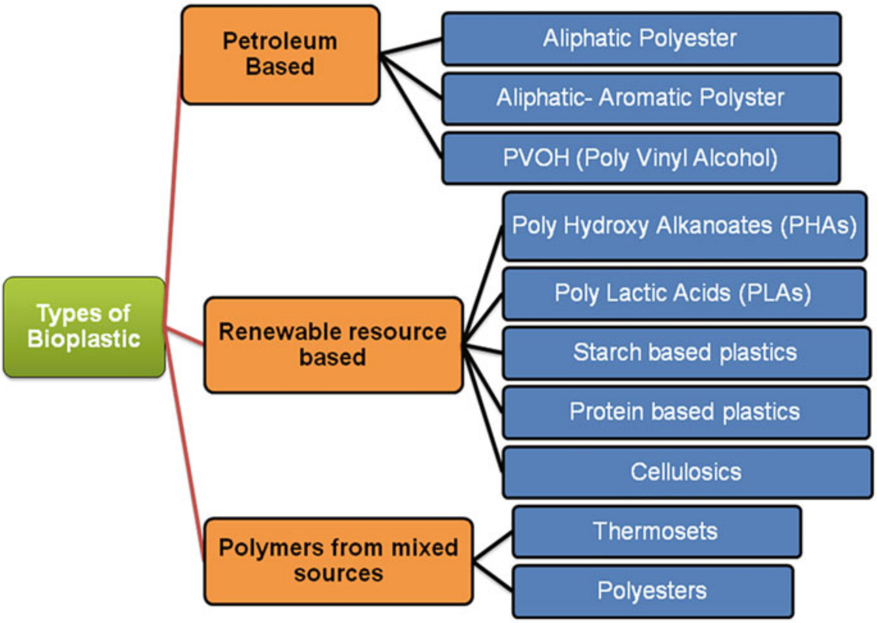

Fig. 15.6 Types of bioplastic used as food packaging material

Table 15.5 Bioplastic based food packaging and its commercial applications

Food types	Types of bioplastic	Company/industry	Reference
Yogurt	Jars made up of PLA	Stonyfield (Danone)	Peelman et al. (2013)
Frozen fries	Films based on PLA (bio-flex)	McCain	Rukhsana et al. (2019)
Freshly cut fruits, vegetables, salads, and bakery goods	PLA trays	Asda (retailer)	Rukhsana et al. (2019)
Coffee and tea	Cups coated with PLA	KLM	Peelman et al. (2013)
Butter	PLA based container	Cyclus (Brasil)	Rukhsana et al. (2019)
Fresh salads	PLA based bowls	McDonald’s	Peelman et al. (2013)
Potato chips	PLA based bags	Snyder’s of Hanover, PepsiCo’s Frito-lay	Blakistone and Sand (2007)
Kiwi fruit	Cellulose film based trays	Walmart	Blakistone and Sand (2007)
Bread	PLA based paper bags	Delhaize	Peelman et al. (2013)
Organic pretzels	PLA bags	PepsiCo’s	Blakistone and Sand (2007)

degradation were most effectively prevented by PLA as compared with other packaging materials (Haugaard et al. 2003). The effect of pasteurization on a meat salad packed in conventional (PE: Polyethylene, PP: polypropylene) and biobased packaging (PLA, PHB: polyhydroxybutyrate) material was investigated and PHB films were found to be suitable packaging materials for this purpose (Levkane et al. 2008). Different studies on cellulose based films also showed that they could be an alternative for packaging several food products.

However, there are some limitations like thermal instability, brittleness, difficult heat sealability, low melt strength, and high oxygen permeability restrict the use of PLA and PHB films for many food packaging applications. Starch and cellulose are hydrophilic by nature. Hence, packaging materials based on these materials have a low water vapor barrier, which leads to poor mechanical properties and limited long-term stability.

15.8.1 Roles of Microbe in the Remediation of Bioplastic Based Packaging Materials

The biodegradation and catabolism of bioplastics are responsible for more than 90 forms of microbes. Degradation of bioplastics by bacteria or fungal organisms is known by the presence of a clear zone surrounding development in a plate comprising the bioplastic as the sole source of carbon, accompanied by analysis of the diameter for the extension of biodegradation.

Destabilization of PHA bioplastic has been found using the PHA biodegradation verification technique by using scanning electron microscopy (Tachibana et al. 2013). Enzymes that may be whether intracellular or extracellular are accountable for bioplastic degradation. Depolymerases group of enzyme, which was derived from microorganisms, has been investigated and was found to play an important role in biodegradation of bioplastics (Chua et al. 2013).

The depolymerase enzyme produced from *Streptomyces thermoviolaceus* is responsible for the degradation of bioplastic (Chua et al. 2013). Certain microbial enzymes including lipase and estrase produced from *Alcaligenes faecalis* and *Comamonas acidovorans*, respectively, involved in bioplastic biodegradation (Trivedi et al. 2016). Soil and compost habitats have been extensively studied, and were found to contain a high number of bioplastic degrading microorganisms (Accinelli et al. 2012). Due to various higher organic content, agricultural soils were reported as an effective site for PLA degrading organisms (Penkhrue et al. 2015).

15.9 Future Prospects and Safety Issues

Antimicrobial packaging is an emerging technology that promises a new approach to food packaging. Despite its current restricted use due to legal issues related to additives, it does not cease to be an innovative viewpoint for the present and future packaging trends. The need for versatility of packaging methods stems from the increasing demand for convenience, safety, and compatibility of food product packaging, combined with the need to create environment friendly solutions to problems. A lot of research is still underway before commercializing innovations. A thorough analysis of the chemical, microbiological, and physiological effects of such systems on food, its consumers, and the environment is the need of the hour. Thus far, strategies and model systems have been studied. Yet a lot of work is to be done on trials with actual food materials and their preservation (Vanderroost et al. 2014).

Potential food applications of antimicrobial films include fish, cheese, bakery product, meat, fruits, and vegetables (Pereira de Abreu et al. 2012; Dobrucka 2013). This is very important to identify the categories of food that will make benefited most from antimicrobial packaging materials. Future research into a mixture of naturally derived antimicrobial agents, bio preservatives, and biobased polymers can highlight a variety of antimicrobial packaging system considering the food safety, shelf life, and environmental friendliness is necessary (Noushin et al. 2017; Soares et al. 2017; Giuseppe et al. 2018). Also, additional analysis is required on utility of plant extracts so as to judge their antimicrobial activity considering its potential side effects in prepackaged foods (Dariusz and Barbara 2014; Zárate-Ramírez et al. 2014). Thus, analysis is required to work out whether or not natural plant extracts may act as each an antimicrobial agent and as an odor/flavor enhancer. Amendments to regulations also require toxicological testing before use (Ye-Chong et al. 2014).

15.10 Conclusion

Several reviews validate the effectiveness of antimicrobial agents to inhibit the growth of microorganisms when incorporated into the packaging materials. Further work has to be carried out in correspondence to the factors affecting inhibitory characteristics of the antimicrobial systems. Very less research has performed about the sensory effects of these additives on food, particularly with respect to plant extract additives that release pungent odors. Further study is also required regarding the effects of additives on the physical characteristics of the film. It should be remembered that, primary objective of active packaging system is to provide healthy and safe food with high quality control standard. In order to set a sustainable environment and prevent the possible disposal of packaging wastes in the environment, production of bioplastics gained a lot of attention due to their biodegradability. The research and development in the area of bioplastic based active packaging system would be helpful to enhance the shelf life of the food products in eco-friendly ways.

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