Food Packaging Development: Recent Perspective

STM JOURNALS

Journal of Thin Films, Coating Science Technology and Application
ISSN: 2455-3344
Volume 6, Issue 3
www.stmjournals.com

Food Packaging Development: Recent Perspective

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Abstract
Latest emerging trends in food packaging has given a boost to food processing industries. There is a continuous demand for the cleaner label without the sacrifice of taste and flavor for healthier ingredients. The quality of the packaged food product, freshness, sensory perception, and convenience are all crucial purchasing factors for the millennial. Recent developments on food packaging materials have reduced the wastages along with enhancing the product quality as well as extending its shelf life and ensuring product safety. This article reviews the innovative developments for the active packaging with emphasis on modified atmospheric, antimicrobial, antioxidant, intelligent packaging, and nanotechnology in food packaging. The emphasis is on the freshness, retaining nutritional quality and after use disappearance of food packaging materials in the soil and water in an environmentally friendly way.

Keywords: *Antimicrobial packaging, antioxidant packaging, flavor releasers, intelligent packaging, MAP, nanotechnology*

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INTRODUCTION

In the exploding populated world, feeding people is a great challenge. More farms are there today than a decade ago. In the future, the global demand for food will be tremendous and the food system role would be to deliver more nutritious food with a wide variety, improved safety with less environmental impacts and greater convenience. It, therefore, requires tremendous development of agricultural food technologies for raw materials, formulation processing, packaging, and temperature control through distribution and merchandising.

Packaging for food production has been used since ages to serve the basic function of containment, protection, information dissemination but the changing market trends and consumer awareness has shifted the focus to novel packaging techniques. Changing lifestyle trends with less time for consumers to prepare their food has posed a challenge for the packaging industry to meet consumer requirements. Apart from the conventional function of product protection and acting as an inert barrier against external environment novel packaging techniques has certain components like antimicrobials, flavor releasers, CO_2 absorbers/emitters, antioxidants, O_2 absorbers in the packaging system which enhance the packaging performance [1] along with prevention of moisture infusion, ripeness indicators, biosensors, ethylene scavengers, aroma emitters, etc. These lead to delay in the enzymatic process, chemical spoilage, preserve the flavor and nutritional quality of the product and enhance its shelf life.

Development in the present millennium is moving at a fast pace and people in developed countries are shifting towards high moisture foods with desired freshness, mild use of preservatives that are safe and healthy to consume. The marketing of such products with longer shelf life requires packaging with the additional improvement which performs some extra functions [2, 3]. The food loss is a major economic concern for the food industry, whereas poor quality food imposes many health problems to the consumers. The presence of spoilage microorganisms is a major reason behind food losses. This requires the development of technology which not only enhances the life of the food but also provides a safer food thus minimizing food losses.

Meat, poultry, seafood and vegetables, and fruits are highly perishable unless properly packaged. Protein denaturation, lipid oxidation and growth of microorganisms due to favorable pH and high water activity [4, 5] reduce the product life span due to spoilage of these foods [6–8]. The packaging has to be carried out carefully for these food products and initial quality has to be retained for a longer time period thus increasing the product life span and also reduces the food waste.

Recently the active focus is on developing polymers made from renewable and sustainable resources to obtain biopolymers having all functionality that can improve food quality and shelf life and are environment-friendly. They are synthesized from the naturally occurring materials such as chitosan, proteins, cellulose, and starch and similar type of raw materials that are easily degradable due to enzymatic action of microorganism into simple nontoxic products and have excellent mechanical properties too. The other examples are polylactic acid (PLA) and polyhydrobutric acid (PHB) which are gaining interest in food industries as packaging materials [9] due to their excellent physical properties and biodegradability.

ACTIVE PACKAGING

The packaging materials are polymeric compounds either blended or grafted and having different functionalities for permeation of gases or vapors or solute. Recent trends require making packaging active by incorporating sachets inside the package or by addition of active agent which makes it environmentally friendly with less chemical utilization such as preservatives or additives. However, their main advantage is for the solid food products and not for the liquid and has other limitations too [10]. Figure 1 presents the classification of the different types of active packaging techniques being used.

Oxygen Scavengers

Oxygen scavengers along with modified atmosphere packaging have been used in the meat industry to preserve the color of red meats and to enhance the visual acceptability of meats [11, 12]. The oxygen scavengers in the package helped to maintain a low oxygen concentration (0.1%) to prevent metmyoglobin concentration.

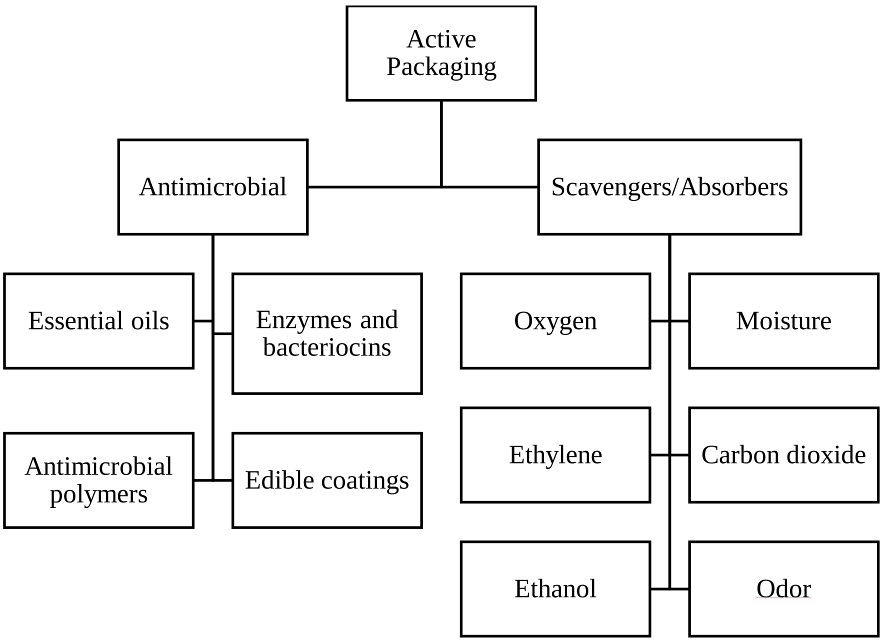

Fig. 1: *Schematic Diagram of Types of Active Packaging.*

The use of iron-based oxygen scavenger for beef packaging was found helpful in reducing drip loss, as well as helped with microbial and sensory properties [13]. The vacuum controlled atmospheric packaging of pork sausages in a 20% CO_2 and 80% NO_2 with iron-based scavenging sachet increased the shelf life in respect to its color and lipid stability for 20 days at a storage temperature of 20°C [14]. In case of bakery products, the use of oxygen absorber sachets along with the food products such as bread, pastries, etc. enhanced their shelf life by inhibiting the mold growth and by also preventing the lipid oxidation thus preventing off-flavor production. These sachets can be used along with modified atmosphere packaging of bakery items to enhance the effect of these sachets [15, 16].

UHT treated milk packed in oxygen scavenging film lined aseptic packaging was found to contain less of the dissolved oxygen and other volatiles associated with the staleness of the milk [17]. In case of cheese, oxygen scavengers were found to act as mold inhibitors [18].

Carbon Dioxide Absorbers/Releasers

Although carbon dioxide is used in modified atmospheric packaging but the accumulation of carbon dioxide in the food product can have a negative effect on the quality of the food product. This is a cause of major concern in the case of carbon dioxide producing foods such as fermented foods and fresh produce. CO_2 levels above a limit can cause physiological injury to the produce. At the same time, there are foods which benefit from high CO_2 concentrations which necessitate the use of CO_2 emitters in the package. CO_2 has an antimicrobial effect and helps in food preservation. Theoretically the absorption or removal of CO_2 from a gaseous phase can be attained by physical adsorption, cryogenic condensation, membrane separation, and a chemical reaction with an alkaline solution. Membrane separation requires high-pressurization equipment whereas the cryogenic separation of CO_2 gas requires refrigeration equipment which makes both technologies unbefitting for food packaging applications. CO_2 scavenging materials can be enclosed in a sachet placed in the food package or fabricated as a sheet or coating.

Calcium hydroxide is the most common CO_2 scavenger used in the food packaging systems. It reacts with CO_2 to produce calcium carbonate and liberate water as a by-product. Calcium oxide, CaO, is often used for CO_2 absorption in large volumes in fresh produce transport vehicles but is not used in small food packages. Magnesium oxide, magnesium hydroxide, sodium chloride, and sodium carbonate are some of the other agents which absorb CO_2 on the basis of a chemical reaction.

CO_2 gas can be adsorbed onto physical adsorbents such as zeolite and activated carbon. Carbon dioxide can be added in many different forms like absorbent pads and moisture-mediated bicarbonate chemicals in packets.

Moisture Regulators

Packaged food products interact with their package environment and may lose or gain moisture thus disturbing the Equilibrium relative humidity (ERH) of the product. Both the loss of moisture or moisture uptake adversely affects the product shelf life and its acceptability. The build-up of moisture in minimally processed and high water activity foods results in microbial proliferation (bacteria and mold growth) as well as causes nutritional and sensory losses to the food as soluble nutrients leach out into the water. This results in decreasing the product acceptability as well as reduces its shelf life. The take up of moisture by low water activity foods affects their texture as well as their consumer acceptability. The use of moisture regulators is an efficient way to overcome such problems.

Moisture regulation technology regulates the temperature fluctuations in the package. It absorbs or desorbs the moisture to stabilize the total moisture content of the package to pre-specified levels. It acts as a buffer by supplying or removing moisture to maintain product stability regardless of temperature change and other fluctuating environmental variables. Moisture regulators can be in the form of sachets, moisture absorbent sheets, pads, etc. [19]. Desiccants such as calcium oxide, calcium chloride, molecular sieves, silica gel are widely used in fruits and vegetables and meat products to absorb the excess moisture present in the package environment [20] while microporous bags or pads of inorganic salts and protected layer of solid polymeric humectants are used to buffer the humidity inside the cartons [19, 20].

Some commonly used moisture regulators are Dri-Loc®, MoistCatch, TenderPac®, Fresh-R-Pax® which accumulate the drip losses and helps in shelf life extension.

Antimicrobial Active Packaging

Foodborne outbreaks are a major concern and to overcome this problem new innovative technologies are developed and one of them is antimicrobial packaging for fresh food products. The main focus is to obstruct the bacteriological growth and retain the quality, freshness and extend the shelf life of the food products. The other significant aspect is to utilize the kind of packaging which is easily degraded in the environmental friendly way [21, 22].

There are various ways by which antimicrobial packaging can be used. The food products are enclosed using sachets/pads/sheets/blankets containing volatile antimicrobial agents into packages. These can be in the form of oxygen and moisture absorbers or generating ethanol vapor. Oxygen and moisture absorbers avert the microbial growth by making anaerobic conditions and thus lowering the water activity. They are normally used in bakery, pasta and meat industry to inhibit oxidation and water condensation [22]. Ethanol vapor generators are used in bakery and dried fish industry to retard mold growth by releasing ethanol into the headspace within the package [23]. Absorbing pads containing organic acids and surfactants are used in trays for packaged retail meats and poultry. These soak up meat exudates and inhibit microbial progression [24]. For the dried food products, the sachets contain silica gel/activated clay along with the activated carbon/iron powder for dual application of moisture, odor absorption or oxygen scavenging are used. Essential oils such as garlic, cinnamon, etc. are also used for sachets application and their antimicrobial activity is due to the presence of diallyl di-, tri-, or tetra-sulfide compounds [25]. Allyl isothiocyanate compounds are plant-based compound and used as sachets for the preservations of cheese products or leafy vegetables as they inhibit yeast or mold growth [26].

Essential oil coating can be applied to the food products as a thin film having antimicrobial activities due to the presence of phenolic compounds. They slowly release antimicrobial agent onto the food surface or migrates to the surface and prolong the product shelf life and prevent the incidence of foodborne illness caused by pathogenic microorganisms. Various essential oils such as *Citrus limonum L., Citrus aurantium L.*, and *Citrus sinensis L., thyme and oregano or germanium dill and marjoram* can be promising antimicrobial agent that can be used for preservation of meat products [27, 28]. Sodium lactate incorporated into cellulose acetate films helped in the preservation of sausages by controlling the microbial population.

In the recent development naturally derived antimicrobial agents are used in packaging of processed meats, cheeses, and other foods which have a relatively smooth product surface coming in contact with the inner surface of the package [29]. Biodegradable film produced by blown extrusion using thermoplastic starch, poly (butylene adipate-co-terephthalate) (PBAT) and 4.5% potassium sorbate as antimicrobial agent increased the shelf life of fresh pasta by regulating the microbial growth [30].

The use of the antimicrobial coating in case of fresh-cut fruits is limited but edible coatings can be used as antimicrobial agents with a perspective to boost the keeping quality of fresh-cut produce [31]. Organic acids (benzoic, acetic, propionic, lactic), polypeptides (peroxidase, lysozyme, nisin, lactoferrin), fatty acid esters (glyceryl monolaurate), plant essential oils (oregano, cinnamon) are some of the potential antimicrobials which can be incorporated into the edible coatings [32]. Postharvest quality deterioration in fresh produce such as berry fruits, apricots, pears, whole cantaloupe and minimally processed broccoli has been delayed with the application of chitosan-based edible coating [33–36]. Being natural these do not pose a harmful health effect.

Addition of oregano essential oil to cassava starch-based biodegradable films enhanced the film mechanical and barrier properties along with providing antimicrobial and antioxidant properties to the film. The films when applied to ground beef enhanced its shelf life due to its antimicrobial activity and also by inhibiting lipid oxidation [37]. Applying oregano essential oil as a surface coating to cassava bagasse based biodegradable trays enhanced the antimicrobial properties of the packaging. The trays were exhibited action against molds, yeast, Gram-positive and gram-negative bacteria and also decreased the water absorption and adsorption properties of the trays [38].

Ethylene Absorbers

Ethylene gas helps in the ripening of the fruits. Climacteric fruits such as bananas, guava tend to produce this gas even after harvesting which results in over-ripening of the produce. Ethylene absorbers just prevent over-ripening of the produce. To extend the ripening process and extend fruit shelf life, and reduce or eliminate ethylene from packages, there are three different mechanisms. They are classified as ethylene action inhibitors, ethylene synthesis inhibitors, and ethylene oxidants responsible for removing it from the environment. Ethylene scavenger compounds, whose aim is to eliminate ethylene from the environment of fresh fruits and vegetables, slowing down the ripening processes and the deterioration of vegetable products, extending the shelf life of fruits and vegetables are commonly used in packaging and are incorporated as a coating or incorporated into the polymer matrix.

Flavor Releasers and Absorbers

Long-term storage of foods in their packaging containers leads to the interaction of food with packaging material in the form of chemical reactions or the packaging products leach into the food. This may lead to some off-flavor production known as scalping or it may lead to the accumulation of the volatile flavor components in the food environment. The migration of chemical compounds leading to off-flavor production results in the reduction of consumer acceptability. This problem can be overcome by either the use of flavor releasers or flavor absorber sachets. The use of flavor releasers can help to improve the sensory characteristics of the food and its overall consumer acceptability as a result of emitting pleasing flavors into the food product [1]. Flavor releaser compounds can be used either with direct contact between food and packaging material or with an indirect contact between them.

Indirect system of flavor release is generally applied for releasing the flavor compounds into solid food products as. Flavor release, in this case, involves three steps as described in Figure 2.

One example of an indirect contact system is PolyIFF® from International Flavor and Fragrances Inc. [39].

Direct system of flavor release is used to deliver aroma and non-volatile flavor compounds into mostly beverage products. Flavor release in this case generally involves five steps which are depicted in Figure 3.

One example of a direct contact system is the chocolate-flavored milk bottle from Add Master [39].

Antioxidant Packaging

Reactive free radicals like superoxide, peroxyl, hydroxyl and alkoxyl and non-radicals such as hypochlorous, hydrogen peroxide, etc. cause the oxidative damage of lipids, nucleic acids and proteins thereby resulting in a change of product texture and color, off-flavors development, toxic aldehyde formation and loss of nutritional value of the product. This is the primary cause of the decline in the shelf life of foods, mainly, meat, poultry, and seafood [40, 41].

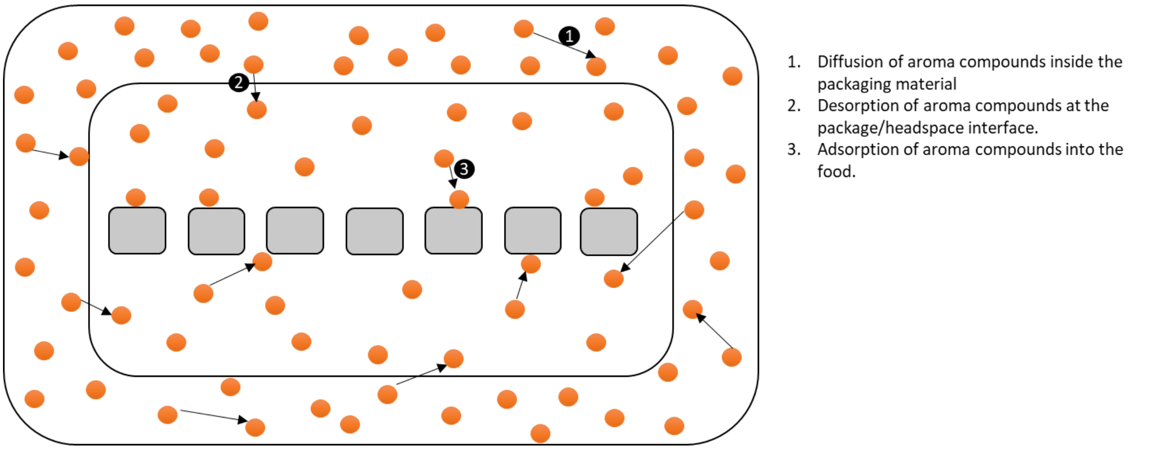

Fig. 2: *Flavor Release in an Indirect System.*

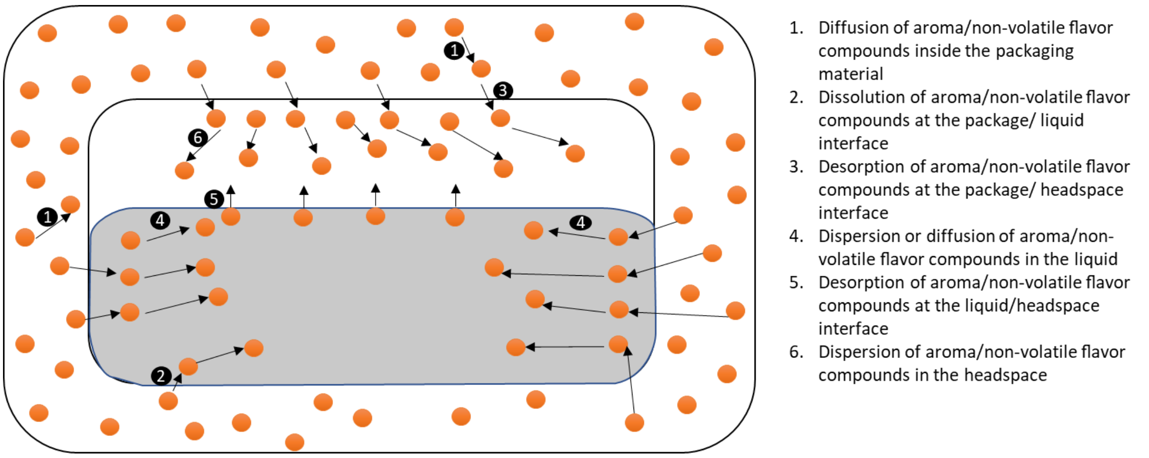

Fig. 3: *Flavor Release from a Direct Contact System.*

This can be overcome by the use of antioxidant packaging system which can be in the form of an independent sachet or pad packed along with the food product or by incorporation of the active ingredient in the packaging material which can either absorb the undesirable compound from the food or release the antioxidant into the food headspace. The sachet or pad contains a compound or a mixture of compounds which either retains or releases a particular gas or vapor whose presence or absence is beneficial for the food.

Use of phenolic compounds like tannic acid, caffeic acid, green tea extracts improved the barrier properties of biodegradable films formed from gelatin and turmeric. They imparted higher tensile strength, low water vapor permeability, and water solubility of films due to the creation of cross-linking. These films when used for the storage of fresh ground pork extended its shelf life due to the antioxidant activity of the added phenolics by preventing the lipid oxidation of the pork samples [13].

Essential Oils

Essential oils have been explored to have a wide range of potential health benefits. They have anti-cancer, anti-inflammatory, anti-diabetic, antiulcerogenic, antidepressant, antianxiety, antioxidant and antimicrobial properties which makes them an option for using in packaging material. When applied to food, EOs can perform an antimicrobial, antioxidant or flavoring function. The most important action of an EO is to minimize or even eliminate the presence of microorganisms and/or reduce the phenomenon of lipid oxidation.

Fernández-Pan et al. (2014) [42] tested the efficacy of oregano and garlic EOs in direct contact with chicken breast and incorporated into a protein matrix. They observed that EOs controlled the microbial action when applied in direct contact, but there was a reduced adhesion and homogeneity of the antimicrobial on the surface of the chicken as compared to their use within a structural matrix, which ensured that antimicrobials were distributed homogeneously and remained ineffective doses during the storage period (13 days).

Winter Savory, cinnamon, clove, Satureja, oregano oils have been used in the biopolymer matrices to impart antimicrobial effect to the packaged food. Lemon, thyme cinnamon has an antibacterial effect and bergamot essential oil has both antibacterial and antifungal effect.

Enzyme and Bacteriocins
Bacteriocins are the antimicrobial peptides produced by lactic acid bacteria and have been used to control the growth of spoilage and pathogenic microorganisms in food [43]. Bacteriocins are generally recognized as safe (GRAS) substances, are generally inactive and nontoxic on eukaryotic cells and the consumers, can be easily inactivated by digestive protease, having little influence on the consumer's gut microbiota, are usually active in wide range of pH and temperature and are relatively broad antimicrobial spectrum against many foodborne pathogenic and spoilage bacteria. This makes them a potent option to be used as an antimicrobial agent [44]. Nisin and pediocin are the common bacteriocins which have been approved and being widely used in the food products [45] but they are ineffective against gram-negative bacteria. Only few purified LAB bacteriocins effective against gram-negative bacteria have been reported. Purified enterocin AS-48 against *Escherichia coli* and purified enterocin E760 against many strains of *Salmonella enterica*, *E. coli*, *Yersinia enterocolitica*, *Yersinia pseudotubercolosis*, *Citrobacteri freundii*, *Klebsiella pneumonia*, *Shigella dysenteriae* and *Campylobacter jejuni* [46].

PLA/SP film impregnated with bacteriocin 7293 had high antimicrobial efficiency against both gram-positive and gram-negative bacteria like *L. monocytogenes, S. aureus, P. aeruginosa, A. hydrophila, E. coli and S. typhimurium* of pangasius fish fillet and had antimicrobial activity of Bac7293 for at least 12 months at 4 °C and 25 °C. This suggested high potential application of PLA/SP + Bac7293 film as a good antimicrobial packaging for pangasius fish fillets [47].

MODIFIED ATMOSPHERIC PACKAGING

MAP involves the changing of the packaging environment either by flushing in a suitable combination of different gases or by changing the permeability of the package to achieve a certain specific composition of gases to achieve an enhanced shelf life, inhibit mold growth and several other benefits [48]. MAP can be either an active MAP or passive MAP. Active MAP involves flushing the package with a fixed composition of gases to prevent the food product from exposure to gases which can reduce their shelf life or result in microbial growth. This composition is then maintained with the help of barrier packaging. On the other hand, passive packaging uses the respiration rate of the product as well as the permeability of the package to achieve the desired steady gas composition [49].

Recent developments in MAP include the use of High-oxygen Modified Atmosphere Packaging, Controlled Modified Atmosphere Packaging and Intelligent modified atmosphere packaging. Use of 80% oxygen and 20% carbon dioxide has been reported to enhance the shelf life of red meat by maintaining the oxymyoglobin and better hygiene quality [50]. However, the high-oxygen content in HiOx-MAP has found to induce lipid oxidation and as well as reduce the tenderness and juiciness of the meat when compared to vacuum packaging of the same [51]. Controlled modified atmosphere packaging (CMAP) involves the initial modification of the gases inside the package and then maintaining the same by the use of silicone membranes made up of silicon rubber which has high permeability towards O_2, CO_2, and ethylene. The use of CMAP conditions has reported increasing the keeping quality of *Salicornia bigelovii Torr.* [52] and *Agrocybe chaxingu* [53] as compared to other storage conditions. They have their sensory quality retained for a longer time and had improved shelf life. Intelligent modified atmosphere packaging involves incorporation of intelligent packaging techniques into a MAP system to achieve desired results. It involves monitoring the freshness of the product depending on the volatiles produces during spoilage, use of time-temperature indicators or RFID tags.

Intelligent Packaging

Packaging which is integrated with a sensor or an indicator which tells about the kinetic changes related to the quality of the product is called intelligent packaging. These packaging systems monitor the quality of the product from production until the endpoint [54]. This packaging technology involves the use of Radio frequency identification (RFID) tags, time-temperature indicators, gas indicators and biosensors for monitoring the quality of the packaged food product. Intelligent packaging systems are gaining importance these days with food safety becoming an important feature connected to the product.

Intelligent and Smart Packaging

Smart packaging provides a total packaging solution that monitors changes in a product or its environment (intelligent) and on the other hand acts upon these changes (active). Smart packaging or biosensors to the way from producers to consumer. Smart packaging allows to track and trace a product to analyze and control the or outside the package to inform its manufacturer, retailer or consumer on the product's condition at any given time. It is used to extend shelf life, monitor freshness, display information on quality, and improve product and customer safety [55]. Intelligent packaging refers to packaging that contains an external or internal indicator to provide information about aspects of the history of the package and/or the quality of the food [56] and the different intelligent packaging techniques are classified in Figure 4.

RFID Tags

RFID uses tags affixed to assets (cattle, containers, pallets, etc.) to transmit accurate, real time information to a user's information system. RFID is one of the many automatic identification technologies (a group which includes bar-codes) and offers a number of potential benefits to the meat production, distribution and retail chain. These include traceability, inventory management, labor saving costs, security and promotion of quality and safety [57].

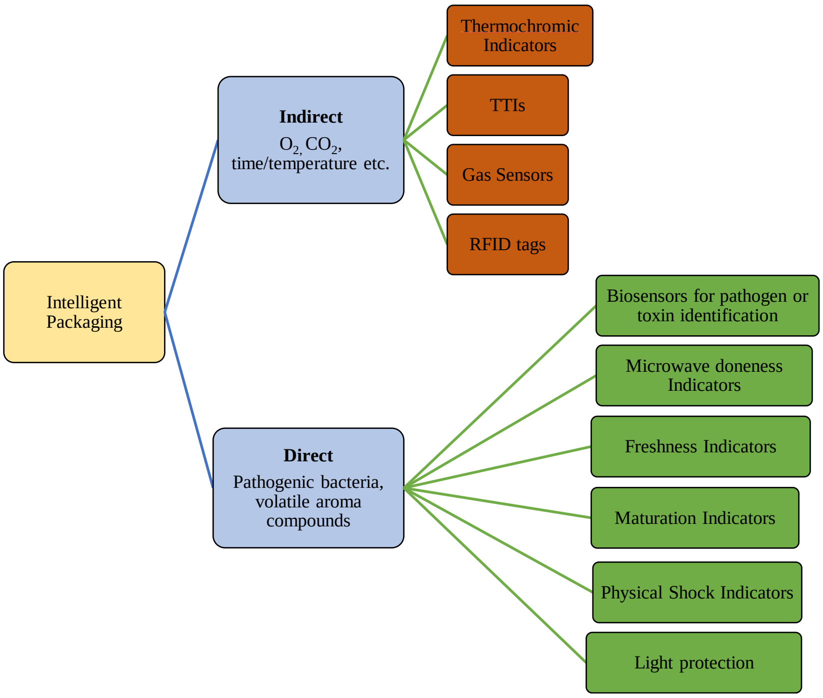

Fig. 4: *Schematic Diagram of Types of Intelligent Packaging.*

RFID tags can be classified according to two types: active tags which function with battery power, broadcast a signal to the RFID reader and operate at a distance of up to approximately 50 m. Passive tags have a shorter reading range (up to approximately 5 m) and are powered by the energy supplied by the reader (giving them essentially unlimited life).

Common RFID frequencies range from low (~125 kHz) to UHF (850–900 MHz) and microwave frequencies (~2.45 GHz). Low frequency tags are cheaper, use less power and are better able to penetrate non-metallic objects. These tags are most appropriate for use with meat products, particularly where the tags might be obscured by the meat itself and are ideal for close-range scanning of objects with high water content [54].

Time-temperature Indicators

Time is an important factor which brings about quality changes in the product during its storage as well as transportation. Due to temperature abuse, it becomes difficult for the product to provide the printed shelf life. Thus monitoring temperature during the entire storage period of the product becomes an important parameter to indicate indirectly the state of quality of the product and helps to determine the actual shelf life of the product. Time-temperature indicators show time-temperature dependent changes that reflect the temperature history of the food product [58]. TTIs are often based on the color change produced in the chromatic indicator due to a pH drop brought about in the product as a result of some temperature-induced reactions [54, 59] or due to change in the color of a polymer coating brought about at a temperature-dependent rate [60].

Gas Indicators

Gas sensors are mainly used in MAP to determine the gas leakage from the package. CO_2 or other gases which are used in the MAP help to maintain the shelf life and quality of the product. A decrease in the concentration of these gases depicts a decrease in product quality. Hence the concentration or leakage of these gases needs to be determined continuously. Gas sensors play an important role in monitoring the gas composition inside the package and indicate about the quality of the product. CO_2 sensors are commonly used in MAP as CO_2 helps in preventing the growth of aerobic bacteria and reduce the metabolic rate of microbes inside the package [61]. CO_2 sensors are either electrochemical-based or optical based. Optical sensors are based on the color change of a pH-based indicator dye or CO_2–induced fluorescence change of a luminescent dye.

NANOTECHNOLOGY IN FOOD PACKAGING

Nanotechnology includes the design, production, and use of devices or structures with one of its sides with a size of 1–100 nm. The reduction of the particle to this size results in the development of certain physical and chemical properties which are different from those of the bulk materials [62]. Nanomaterials are produced by various methods such as grinding, laser technology or vaporization and cooling. Other methods include self-assembled layer formation, solvent extraction, biomass reaction, etc. Nanotechnology plays an important role in modern packaging solution ranging from barrier packaging materials using nanocomposites, nano-particle based antimicrobials to sensors used for detecting changes in the food product. Figure 5 shows the different nanotechnology techniques used in packaging. Cassava-based biodegradable packaging films containing lycopene nanocapsules increased the tensile strength, elongation of the film. It also provided a greater barrier to light transmission UV/Vis compared to the control films and the commercial polyethylene film. When used for storage of sunflower oil, it prevented its oxidation and enhanced the shelf life. The prepared films had a rapid biodegradability for 15 days thus showing the potential of lycopene nanocapsules to be used for active biodegradable packaging [63].

Nanosensors

Incorporation of nanosensors in the food packaging will play a vital role in the future. Nanosensors detect the spoilage of food by sensing the change in the color of the product or by sensing the gas formed due to spoilage of the product such as hydrogen, hydrogen sulfide, nitrogen oxides, Sulphur dioxide and ammonia [64].

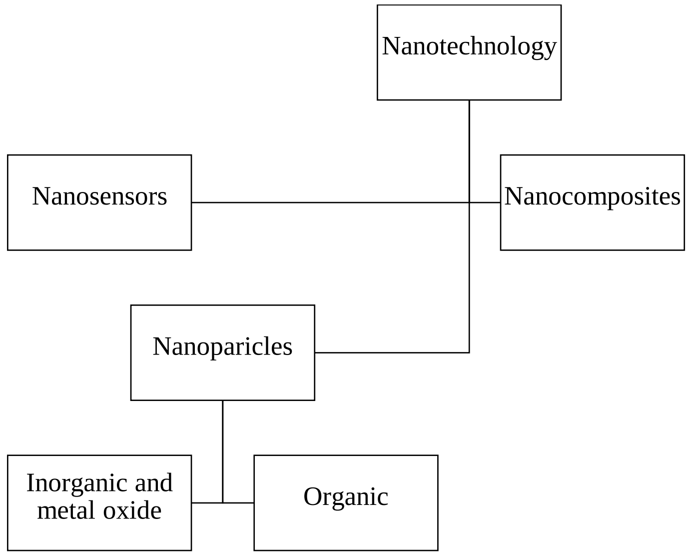

Fig. 5: *Schematic Diagram of Different Nanotechnology Techniques Being Used.*

The sensors are made up of a data processing unit along with a sensing part which can either detect the color change, gas formation or chemical compound converting it into electronic signals [65]. Nanosensors have been used in the detection of pesticides in fresh fruits and vegetables, carcinogens in food materials [66], adulteration in food and beverages [67], pathogens such as *Staphylococcal enterotoxin B* and *cholera toxin* [68], detection of volatile organic compounds [69] and temperature abuse indication [70]. Nanosensors used for food packaging can be metal (palladium, platinum and gold) based nanosensors used for detection of aflatoxin B1 in the milk [66], detection of color change or gas production in the food due to spoilage [64]or the discovery of any change in light, heat, humidity or gas into electric signals [71]. Single-walled carbon nanotubes and DNA have found use in the detection of the pesticides on fruits and vegetable surface [72]. Carbon black and polyaniline nanosensors have been used for the detecting carcinogens present in the food materials [73], detection of microorganisms that infest the food [74] and for the detection of foodborne pathogens [75]. Surface plasmon-coupled emission biosensor (with Gold) have also been used to detect pathogenic organisms [76].

Abuse indicators, a type of nanosensors have been used to determine if the anticipated temperature has been attained or not. Full-time-temperature history nanosensor records time-temperature combinations over a period of time and are used to detect temperature changes in frozen foods [77]. iStrip of time-temperature indicator assists in the detection of spoilage of food based on the temperature history [78].

Nanocomposites

Nanocomposites are polymer materials made in conjugation with nanoparticles to enhance the properties of polymers [79]. Nanoparticles impart chemical functionality, stability to heat and cold are achieved, excellent barrier properties to the polymer material and helps to enhance the shelf life of the stored. They inhibit insect infestation inside a packaged food, good barrier property against carbon dioxide leakage from carbonated beverages. Nanoclays have been used effectively to impart these gas barrier properties. Aegis, Imperm, and Durethan are commercially available nanoclays which are biodegradable in nature [80]. Aegis is a good oxygen scavenger and retains CO_2 in carbonated beverages [79]. Durethan provides stiffness to paperboard packaging for fruit juices [81] and Imperm is a good oxygen scavenger [82]. Nanoclay (polymer and nanoparticles) reduces the leakage of carbon dioxide from carbonated beverage bottles by creating efficient gas barriers [79]. Nanocor prevents such leakages in plastic beer bottles [80]. Zinc oxide and pediocin and silver-coated nanocomposites act as an antimicrobial agent [83], degrade the lipopolysaccharide [84] and cause irreversible damage to the bacterial DNA [85].

Bio-nanocomposites (cellulose and starch) are efficient layering material for packaging applications. Top Screen DS13 and Guard IN Fresh helps in the ripening of fruits and vegetables by scavenging ethylene gas [86]. NanoCeram PAC helps in rapid absorption of unpleasant components which may cause foul odor and create repulsive taste [86].

Nanoparticles

Nanoparticles which have earlier been used in the drug delivery system are now being used in food packaging to exert barrier properties and antimicrobial properties. Silver nanoparticles (AgNPs) are strong antimicrobials against various bacteria [87] and even against those which are resistant to other chemical antimicrobials. AgNPs also absorb and decompose ethylene and hence extend fruits and vegetable shelf life [88]. AgNPs catalyze free radical formation in the bacterial cell which results in cell death due to oxidative stress. AgNPs also bind to membrane proteins causing pits in the cell structure and resulting in morphological changes and cell death due to variation in molecular transport and ion balance within the cell. They are also found to react with phosphorus groups of DNA thus resulting in cell death. These nanoparticles create functional antimicrobial materials when incorporated into the polymer. Controlled release of these particles into the food can keep the food microbiologically safe for a long time. Along with silver nanoparticles, titanium dioxide nanoparticles can also be used as potent antimicrobials for packaging applications. Chitosan and gelatin which are well known for their biodegradable properties when fabricated into nanocomposite films using polyethylene glycol and silver nanoparticles (AgNPs) resulted in enhancing the mechanical properties and a decrease in light transmittance through the film. These films also resulted in enhancing the shelf life of red grapes as compared to control chitosan and gelatin-based films [89].

Silicon dioxide nanoparticles have helped to reduce the leakage of moisture from packaged food [90]; they act as anticaking and drying agent [91] and absorbs the water molecules in food, showing hygroscopic applications [92].

Titanium dioxide nanoparticles act as food colorant [92], act as photocatalytic disinfecting agent [93] and are used as food whitener for food products such as milk, cheese, etc. [94]. Polymeric nanoparticles are known to be efficient delivery systems and have bactericidal properties [88].

Green Packaging

Polymers used in the packaging industry are fossil-based polymers and their production causes the environment to be disturbed due to increasing the effect of gases like methane, SO_2, nitrous oxide, and raising the level of CO_2 in the ecosystem which finally results in misbalance in climate pattern and subsequently, devastating disasters will occur. Various harmful gases including alkenes, alkanes, aromatic and chlorinated hydrocarbons are emitted during incineration of synthetic polymers.

Green polymers can be an alternative to these polymers as they do not pose any environmental risk and are easily degradable. They can be produced from both renewable and synthetic materials. Green polymers are categorized into synthetic polymers and bio-based polymers which are totally or partially produced from natural polymers such as proteins, polysaccharides, and lipids; and poly-blends made from a mixture of bio-based and synthetic polymers, or biopolymer blends. A bio-based material is defined as a product partly or wholly obtained from biomass, a material of biological origin. However, some polymers like PLA containing building blocks derived from sugars are also considered as bio-based products. Most of these bio-based materials have certificates proving they can be utilized in food-contact applications.

Bio-based polymers can be directly isolated from biomaterials such as polysaccharides, protein, and lipids or can be produced by chemical synthesis using bio-based monomers such as polylactic acid (PLA).

Edible coatings used in packaging are also green packaging. Edible polymers are considered as polymeric materials easily consumed by human beings or animals through oral cavity which do not give harmful effect to the health. Direct utilization of edible polymers on the product surface can provide additional protection to retain the quality and stability of the product.

CONCLUSION

Recently there are many great developments achieved in the packaging sector of the food industry. The innovations were due to the constant research is driven sources and also due to the increased consumer awareness for food quality and safety. The recent developments were focused on delaying oxidation or inhibiting oxidation and moisture regulation, microbial growth, respiration rates and controlling off-flavors and aromas. The awareness about the environmental impact has led to the advancement in the biodegradable packaging materials which reduce food loss and have less impact on the environment. The advancement in active and intelligent packaging leads to an improved level of food safety and quality and transparency to consumers. Nanotechnology will have a great impact in modern packaging solution ranging from barrier packaging materials using nanocomposites, nano-particle based antimicrobials to sensors used for detecting changes in the food product. The future of food packaging is the development of bio nanocomposite materials and polymers with enhanced performance and reduces environmental impact.

Conflict of Interest Statement

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Cite this Article
Neela Emanuel and Harloveleen Kaur Sandhu. Food Packaging Development: Recent Perspective. *Journal of Thin Films, Coating Science Technology and Application*. 2019; 6(3): 13–29p.