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# Recent innovations in food packaging: A Review

**Anmol Lamba[1], Veena Garg[2]**
[1] Research Scholar, Department of Food and Nutrition, Bhagat Phool Singh Institute of Higher Learning, BPSMV, Sonipat, Haryana, India
[2] Dean, Faculty of Science, Department of Food and Nutrition, Bhagat Phool Singh Institute of Higher Learning, BPSMV, Sonipat, Haryana, India

## Abstract

Innovative and novel food packaging techniques are evolving in response to consumer demands for minimally processed, more natural, fresh and convenient food products. The rising issues of food borne microbial outbreaks which demands the use of packaging with antimicrobial effects also lead to innovation in food packaging technology. Novel concepts of active and intelligent packaging play an important role by offering numerous innovative solutions for extending the shelf-life and improving or monitoring the food quality. Active packaging refers to the incorporation of certain additives into packaging film or within packaging containers with the aim of maintaining and extending product shelf life. Intelligent packaging system is capable of sensing and providing information about the function and properties of packaged food and also monitors the condition of packaged food or the environment surrounding the food. The objective of this review is to provide an overview of the current commercial applications of food packaging and recent developments in different types of food packaging technologies.

**Keywords:** Innovation, shelf-life, active packaging, intelligent packaging

## Introduction

Packaging acts as a physical barrier to protect food from external factors, so the stability of packaging materials is absolutely vital for enhancing food quality and safety and increasing shelf-life, as well as ensuring that packaging materials can fulfil their role in providing sturdy, attractive, economical, and convenient products to consumers [1] Food packaging technology is continuously evolving as a result of growing challenges from a modern society. Major current and future challenges to fast- moving food packaging include legislation, global markets, longer shelf life, convenience, safer and healthier food, environmental concerns, authenticity and food waste [2].

The packaging is used to protect the product from the deteriorative effects of environmental conditions such as light, heat, moisture, pressure, microorganisms and so on [3]. Novel and innovative food packaging techniques are evolving in response to consumer demands or industrial production trends towards mildly preserved, fresh and convenient food products with prolonged shelf-life. In addition, changes in retailing practices and consumers lifestyle, present major challenges to the food packaging industry which also act as driving forces for the development of novel and improved packaging concepts [4]. Another important reason for innovative food packaging is the rising issues of food borne microbial outbreaks which demands the use of packaging with antimicrobial effects along with retention of food quality [5]. Packaging optimisation strategies such as varying pack sizes to help consumer buy the right amount and designing packaging to maintain food quality and increase its self life have been proposed to reduce food waste [6]. The major functions of food packaging include convenience, point of purchase marketing, material reduction, safety, tamper-proofing and environmental issues [7].

Innovations in packaging started earlier in the form of electrically driven packaging machinery, metallic cans, aseptic packaging, flexible packaging, aluminium foils and flexographic printing. Additionally, the introduction of various materials, viz. Polyester, polypropylene and ethylene vinyl alcohol polymers led to drastic evacuation from metal, paperboard and glass packaging to plastic and flexible packaging. Later on more advancement in packaging technology appeared as intelligent or smart packaging and active packaging [8]. New concepts of active and intelligent packaging play an increasingly important role by offering numerous innovative solutions for extending the shelf-life and improving or monitoring the food quality. Introduction of active and intelligent packaging can extend the shelf life of food or improve its organoleptic properties and thus prevent food losses [9].

## Active Packaging

Active packaging is one of the innovative food concepts that have been introduced in response to continuous changes in consumer demands and market trends. The purpose of the active packaging is the extension of the shelf-life of the food and the maintenance or even improvement of its quality [10]. Active packaging refers to the incorporation of certain additives into packaging film or within packaging containers with the aim of maintaining and extending product shelf life [4]. Active packaging, however, allows packages to interact with food and the environment and play a dynamic role in food preservation [11, 12]. The principles behind active packaging are based either on the intrinsic properties of the polymer used as packaging material itself or on the introduction (inclusion, entrapment etc.) of specific substances inside the polymer [10, 13]. In active packaging, nanotechnology has a great interesting potential because nanostructures display a high surface-to-volume ratio and specific surface properties. Nanotechnologies such as nano (bio)composites and electro spun nano-fibre based structures are able to enhance desired properties or to introduce new additional effective functionalities with small amount of nanofillers [14].

Active packaging systems can be divided into active scavenging systems (absorbers) and active-releasing systems (emitters). Whereas the former remove undesired compounds from the food or its environment, for example, moisture, carbon dioxide, oxygen, ethylene, flavour or odour, the latter add compounds to the packaged food or into the headspace, such as antimicrobial compounds, carbon dioxide, antioxidants, ethanol [15].

### Active Scavenging Systems (Absorbers)

**Oxygen Scavengers:** The presence of oxygen in a package accelerates the oxidative deterioration of food. Oxygen facilitates the growth of aerobic microbes, off flavor and odour development, colour changes and nutritional losses. Therefore control of oxygen levels in food packages is important to limit the rate of such spoilage reactions in food [3, 16]. The deterioration in quality of oxygen sensitive products can be minimised using oxygen absorbing systems that remove the residual oxygen after packaging [17]. The oxygen absorbers are designed to reduce oxygen levels to less than 100 ppm in package headspace. Existing oxygen scavenging technologies are mainly based on iron powder oxidation, ascorbic acid oxidation, photosensitive dye oxidation, enzymatic oxidation (e.g. glucose oxidase and alcohol oxidase), unsaturated fatty acids (oleic acid and linolenic acid) or immobilised yeast on a solid substrate [6, 18]. Majority of currently available oxygen scavengers are based on iron powder oxidation in the form of small sachets containing various iron based powders containing as assortment of catalysts [3].

**Moisture Scavengers:** A major cause of food spoilage is the presence of excess moisture. Increase in moisture makes the products more prone to microbial spoilage and may cause alterations in texture and appearance, consequently reducing shelf-life [15, 19]. Excess moisture cause food spoilage which can be reduced by using various absorbers or desiccants which in turn lower the water activity of the product to suppress the microbial growth [3]. Active moisture scavengers can be distinguished into 2 main types: RH controllers that scavenge humidity in the headspace, such as desiccants, and moisture removers that absorb liquids [20]. The latter can be applied in the form of pads, sheets, or blankets, and are typically placed underneath fresh products in different packaging concepts (MAP, vacuum, skin pack, and so on). They are applied for foods of high water activity: fish, meat, poultry, fruits, and vegetables [19].

**Carbon dioxide Scavengers:** Carbon dioxide scavengers are used to remove excess $CO_2$ in packages. The carbon dioxide scavengers are particularly used in packing fresh roasted or ground coffees that produce significant volumes of carbon dioxide. A mixture of calcium oxide and activated charcoal has been used in polyethylene coffee pouches to scavenge carbon dioxide. Dual-action oxygen and carbon dioxide scavenger sachets and labels are more common and are commercially used for canned and foil pouched coffees in Japan and the USA [10, 21]. The reactant commonly used to scavenge $CO_2$ is calcium hydroxide, which, at a high enough water activity, reacts with $CO_2$ to form calcium carbonate: $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$. A disadvantage of this $CO_2$ scavenging substance is that it scavenges carbon dioxide from the package headspace irreversibly and results in depletion of $CO_2$, which is not always desired [22].

**Ethylene Scavengers:** Ethylene is a natural plant growth hormone which accelerates respiration of fruits and vegetables, induces fruit ripening, fruit softening and senescence even at low concentration [3]. The control of ethylene in stored conditions plays a key role in prolonging the post harvest life of many types of fresh produce [23]. Ethylene scavengers are useful for preserving ethylene-sensitive fruits and vegetables such as apples, bananas, mangos, tomatoes, onions, carrots [10]. Activated carbon base with various metal catalysts removes ethylene effectively. Activated charcoal impregnated with palladium catalyst is also used to scavenge ethylene from fresh produce [24]. Various films such as silicon polycarbonates, polystyrenes, poly-ethylenes and polypropylenes are also used for ethylene scavenging [20]. Use of 1-methylcyclopropane (1-MCP) is another alternative to minimize the effect of ethylene [25].

**Flavour or Odour Scavengers**: The volatile compounds such as aldehydes, amines and sulphides accumulate inside the package as a result of food degradation can be selectively scavenged [19]. Volatile amines formed due to the protein breakdown in fish muscle can be removed by incorporating acidic compounds like citric acid in polymers [3]. The ANICO bags (Japan) made from film containing ferrous salt and an organic acid such as citric acid or ascorbic acid is capable of oxidizing the amines [21]. Use of high barrier packaging materials can also prevent the absorption of other non-food odour like taints [8]. Flavour scavengers prevent the cross contamination of pungent odour while transportation of mixed loads [3].

### Active Releasing Systems (Emitters)

**Antioxidant Releasers:** Inclusion of antioxidants in packaging materials is an alternative of oxygen scavenging system to prevent food oxidation. Oxidative process is one of the primary causes of quality deterioration of food products [26]. Thus, different antioxidants have been used to inhibit the oxidation in food. However the incorporation of antioxidants in food formulations may affect the food quality parameters such as colour or taste. Active packaging represents an innovative strategy to incorporate antioxidants in a polymer to prevent oxidative processes and extend the self life of food products [27]. Synthetic antioxidants, such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) have been widely used in food packaging to prevent lipid oxidation. There is now growing interest in the inclusion of natural antioxidants such as polyphenols, tocopherols, plant extracts, and essential oils (EOs) to active packaging materials [28, 29, 30].

**Antimicrobial Packaging:** Antimicrobial food packaging is designed to inhibit the growth of spoilage and pathogenic microorganisms. To control undesirable microorganisms on foods, antimicrobial substances are incorporated in or coated onto food packaging materials [3]. The antimicrobial agents generally used on packaging materials include organic acids, e.g. propionate, benzoate and sorbate; bacteriocins, e.g. nisin, extracts from spices and herbs, e.g. rosemary, cloves, horse radish, mustard, cinnamon and thyme; enzymes, e.g. peroxidase, lysozyme and glucose oxidase; chelating agents, e.g. EDTA and antifungal agents, e.g. imazalil and benomyl. The major potential food applications for antimicrobial films include bread, cheese, fruit and vegetables [31].

**Carbon Dioxide Releasers:** Carbon dioxide is added to the packaging environment to suppress the microbial growth in certain food products such as fresh meat, poultry, fish, cheese, and baked goods and to reduce the respiration rate of fresh produce [12]. High carbon dioxide levels (10 -80%) are desirable for such food items in order to inhibit surface microbial growth and extend shelf life [10]. In the case of oxygen scavenger packs, oxygen removal creates a partial vacuum that may result in the collapse of flexible packaging. Additionally, when a package is flushed with a mixture of gases including $CO_2$ and $O_2$, the $CO_2$ dissolves in the product and can create a partial vacuum due to the solubility of $CO_2$ at lower temperatures [32].

**Ethanol Emitters:** Ethanol is an antimicrobial agent particularly effective against mold but can also inhibit the growth of yeasts and bacteria and thus increases the self-life of food products [14]. Ethanol can be sprayed directly onto food products just prior to packaging. A practical and safer method of generating ethanol is through the use of ethanol emitting films and sachets [21]. When food is packed with an ethanol-emitting sachet or film, moisture is absorbed by the food and ethanol vapour is released and diffuses into the package headspace. Ethanol emitters are used extensively to extend the mould-free shelf-life of high-ratio cakes and other high moisture bakery products [4, 33].

## Intelligent Packaging

Intelligent packaging is designed to monitor the condition of packed food or the environment surrounding the food [34]. Intelligent packaging system is capable of sensing and providing information about the function and properties of packaged food and also provides assurance of pack integrity, tamper evidence, safety and quality of the product during the whole food chain [35, 36]. The package will provide information not only about the product itself (origin, expiration date, composition), but will also be able to inform about the history of the product (storage conditions, headspace composition, microbial growth, etc) [6]. It is an extension of the communication function of traditional packaging and communicates to the consumer based on its ability to detect, sense and record the changes in the products environment [6, 37]. Besides, intelligent packaging systems attached as labels, incorporated into, or printed onto a food packaging material offer enhanced possibilities to monitor product quality, trace the critical points, and give more detailed information throughout the supply chain [38]. It also contributes in improving Hazard Analysis and Critical Control Points' (HACCP) and Quality Analysis and Critical Control Points' (QACCP) systems, which are developed to detect the unsafe food, identify potential health hazards and establish strategies to reduce or to eliminate their occurrence [39]. Basically, intelligent packaging devices include indicators, sensors or radiofrequency identification (RFID) [40].

### Indicators

Indicators can be defined as substances that indicate the presence, absence or concentration of another substance or the degree of reaction between two or more substance by means of a characteristic change, especially in colour [16].

### Time Temperature Indicator (TTI)

Temperature is one of the most important environmental factors determining food preservation, as variations in temperature during transportation, handling, distribution, storage, and consumption can compromise the safety and self life of perishable of food products [41]. To limit pathogenic microorganism growth or toxin formation in most perishable products, the FDA has defined these foods as TCS (time and temperature control for safety) foods that requires time and temperature control to ensure their quality and safety [42]. Therefore, temperature monitoring is vital to provide consumers with necessary information about food quality and safety throughout the process of food circulation. To address this issue, TTIs have been developed to monitor time- and temperature-dependent changes in product quality [32]. Time temperature indicators are meant to give information on whether a threshold temperature has been exceeded over time and or to estimate the minimum amount of time a product has spent above the threshold temperature. Basically TTIs are small tags or labels that keep track of time-temperature of a perishable commodity from the point of production to the end consumer [3]. TTIs are generally attached onto individual consumer packages or shipping containers. There are three basic types of TTIs available in market: (1) critical temperature indicators (these only show whether a product has been exposed to a temperature above, or sometimes below, a reference temperature); (2) partial history indicators (these indicate the cumulative effect of the time-temperature changes on product quality or safety when a product has been exposed to a temperature above a reference temperature); and (3) full history indicators (continuous monitoring of the manner in which the temperature varies with time throughout a product's history) [43].

### Integrity Indicator

Integrity indicators attached to the packaging ensure the integrity of the package in the distribution chain. The tag is activated at the time of consumption, when the seal is broken it triggers a timer and a color change is experienced over time [6]. Gas indicators are most commonly used integrity indicator for meat packaging applications. Among the various types of gas indicators, oxygen indicator is the most common indicator used for MAP packaging applications [44]. MAP of meat products other than fresh meat usually consist of high levels of $CO_2$ and a residual concentration of $O_2$. Therefore a leak in MAP package is easily detected using indicators of the level of oxygen. The most common $O_2$ indicators are colourimetric redox dye based indicators comprising a redox dye such as methylene blue, and a strong reducing agent, such as glucose in an alkaline medium [45]. A commercially available patented (Ageless Eye, Vitalon, and Samso-Checker) indicators provide information about the oxygen and carbon dioxide leakage in meat products [45, 46].

### Freshness Indicator

Freshness indicators provide the information resulting from microbial growth or chemical changes within a food product. The microbiological quality of the product may be determined through the reactions between integrated indicators within the package and microbial growth metabolites [47, 48]. Changes in concentration of metabolites such as glucose, organic acids, ethanol, carbon dioxide, biogenic amines, volatile nitrogen compounds or sulphuric compounds during storage indicates microbial growth. Typically, these indicators focus on the detection of the first kind of change (pH, gas composition, etc.). These changes are detected by the indicators and transformed into a response, usually a colour response which can be easily measured and correlated with the freshness of food [49]. A variety of freshness indicators have been developed to monitor the chemical changes occurring during the self life, the majority of which are based on colour change of indicator tag due to the presence of metabolites derived from microbial growth.[47]. A number of developments have been announced by packaging companies but most of them did not achieve a successful commercialization. In 1999, COX Technologies, USA launched FreshTag® colourimetric indicator labels that react to volatile amines produced during storage of fish and seafood products, however the product was discontinued in 2004 [6, 16]. VIT Technical Research Centre of Finland together with UPM Raflatac developed a freshness indicator for poultry meat based on a nanolayer of silver that reacts with hydrogen sulphide, a breakdown product of cysteine. The indicator is opaque light brown at the time of packaging, but as silver sulphide is formed the colour of layer is converted to transparent. However, Raflatac indicator is not commercially available [6, 47].

### Sensors

A sensor is a device used to detect, locate or quantify energy or matter, giving a signal for the detection or measurement of a physical or chemical property to which the device responds and provides a continuous output of a signal [50]. Most sensors contain two basic functional units: a receptor and a transducer. In the receptor, physical or chemical information is transformed into a form of energy, which may be measured by the transducer. The transducer is a device capable of transforming the energy carrying the physical or chemical information about the sample into a useful analytical signal [46].

### Biosenser

Biosensors consist of bioreceptors and transducers.[51] The bioreceptor recognizes the target analyte and the transducer converts biochemical signals into quantifiable electronic response.[44] In biosensor, receptors can be either organic or biological materials like enzyme, hormone, nucleic acid, antigen, microbes etc. The transducers may be of optical, acoustic or electrochemical [3]. A biosensor is developed by Pospiskova *et al*. for the detection of biogenic amines formed due to the decarboxylation of amino acids or by amination and transamination of aldehydes and ketones due to microbial action [52]. Food Sectinel System® (SIRA Technologies Inc.) is a commercial biosensor developed to detect the food pathogens. Specific antibodies are attached to the membrane forming part of the sensor or the barcode. The pathogens cause localized dark bar formation results the barcode unreadable [44].

### Gas Sensor

The composition of gas within food packaging changes due to the activity of the food product (such as respiration, transpiration and spoilage due to microorganisms), the nature of the package (such as the gas permeability of the packaging material), and the environmental conditions (temperature or package leaks), and it is directly related to the integrity, shelf-life, quality, and safety of packaged food products [44, 53]. Different types of gas sensors are used in food packaging to monitor the changes in gas composition inside the package. It include oxygen sensors, carbon dioxide sensors, water vapour sensor, ethanol sensor, etc [46, 50] Oxygen can cause deleterious effects on food quality through oxidative rancidity, changes in color, and microbial spoilage; therefore, oxygen sensors are widely used in food packaging [53]. Papkovsy *et al*. described the optical oxygen sensors which are based on the principle of luminescence quenching or absorbance changes caused by direct contact with the analyte [54]. Optochemical sensors are used to detect the quality of products by sensing gas analyte such as hydrogen sulphide, carbon dioxide and volatile amines [55]. A carbon dioxide indicator is developed by Chatterjee and Sen to respond to the presence of carbon dioxide via a colour change from red to yellow [56].

### Electronic Nose

Electronic Nose is an analytical tool composed of an array of either chemical or biosensors with partial specificity and statistical methods enabling the recognition of simple to complex flavour, odour or savour [40, 57]. It generates a unique response to each flavour, odour or savour. An array of sensors respond to volatile compounds by changing their electrical properties [58]. Then the samples can be classified as acceptable or unacceptable, referencing a sensory evaluation or microbiological analysis catalog. The response of the electronic nose has been found to be consistent with microbiological analysis and volatile concentration determination of the product [59]. Electronic nose has been proved successful in the quality evaluation of fresh Yellow fin tuna and vacuum-packaged beef [58].

### Radiofrequency Identification (Rfid)

Radiofrequency identification (RFID) is an automatic identification technology which is based on wireless communication (magnetic field or electromagnetic wave) that can provide real-time information about temperature, relative humidity, and nutritional and supplier information as the product moves through the supply chain [60]. It does not fall into either sensor or indicator classification but rather represents a separate electronic information-based form of intelligent packaging [61]. RFID uses tags which can be embedded in an item or placed inside food packing [62]. Most RFID tags store some sort of identification number based on which reader can retrieve information about the ID number from a database and acts upon it accordingly [63]. RFID tags can be classified as passive, semi-passive, or active according to its power supply mode. Passive tags do not contain onboard power sources and are powered by electromagnetic induction in magnetic fields. Passive tags rely on the power supplied by the reader [60]. Semi-passive tags have a local power source that is used only for powering the chip. These tags still rely on the reader for electromagnetic wave emission, and most of the time they remain dormant except when awakened by the reader. Thus, the power source is inactive most of the time, which increases the lifespan of the tags. Active tags have an embedded battery that is used to power the chip and to broadcast signals to the reader. In comparison to the other two types of tags, these tags have the widest reading range (more than 50 m), and many tags can be read simultaneously. However, the widespread use of active tags is limited, because they are more expensive than passive or semi-passive tags and have a limited lifespan (depending on battery life) [62]. RFID technology has been available for approximately 40 years but its broad application to food packaging is relatively a recent development [46]. It has been successfully applied to traceability control and supply chain management processes because of its ability to identify, categorize and manage the flow of goods [64, 65].

## Conclusion

Novel food packaging technologies are the result of ever-increasing demand of consumers for safe and high quality foods. The innovations in packaging system assist in detecting, monitoring, tracking, recording and communicating the quality of food products throughout the supply chain. Active and intelligent packaging helps in extending the shelf life of food products and also enhances the safety and security of food. Further, food products are very complex systems and packaging parameters are highly product-specific. Therefore, it is very crucial to consider all the influencing factors (such as the physical and chemical properties of the food, packaging material and its size, storage conditions, etc) during the adoption of packaging techniques.

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