MAP, Active and Intelligent Packaging

Remya S.
Fish Processing Division
ICAR-Central Institute of Fisheries Technology, Cochin
Email: remya03cof@gmail.com

1.0 Introduction

Food packaging plays a very important role in the food supply chain, which can be used as a protective layer to prevent contamination of food and maintain food quality. However traditional packaging system only isolates food from the external environment and cannot provide food freshness information for producers, sellers and consumers. The presence of O_2 in standard air packing will cause the spoiling process to proceed more quickly. Advanced food packaging techniques refer to innovative methods and technologies used to package and preserve food products. These techniques go beyond traditional packaging approaches and aim to enhance food safety, extend shelf life, improve convenience, and reduce environmental impact. By using vacuum packaging or packaging with a changed atmosphere, it is possible to overcome the issue of shelf life. In reduced oxygen packaging, the oxygen levels inside the package are significantly reduced, typically by displacing oxygen with other gases or by creating a vacuum. The reduced oxygen environment can be achieved through various methods, including modified atmosphere packaging (MAP) and vacuum packaging. Smart packaging such as active and intelligent packaging technologies, is considered as an innovative packaging technique for the development of wide variety of products with competitive cost and achieved a great position in the preservation of different food systems. It is a fast-growing technology. The global smart packaging market size was estimated at USD 35.92 billion in 2022 and is expected to reach around USD 60.49 billion by 2032 with a registered CAGR of 5.4 % from 2023 to 2032.

2.0 Modified Atmospheric Packaging

Modified Atmosphere Packaging (MAP) can be defined as the enclosure of food in a package in which the atmosphere inside the package is modified or altered to provide an optimum atmosphere for increasing shelf life and maintaining food quality. MAP is the imposition of a gas atmosphere, typically containing an inert gas, such as nitrogen combined with an antimicrobially active gas, such as carbon dioxide, upon a packaged food product to extend its shelf life. MAP can significantly extend the shelf life of food products, thus prolonging the distribution chain and diminishing the need for centralized production. MAP provides an added barrier against spoilage, and can therefore improve shelf life and enhance product safety. MAP is inexpensive, easy to apply, and suitable for a wide range of packaging machinery and production venues. However, food manufacturing and transport to the end user is a complex process to which MAP contributes only a partial solution regarding shelf-life problems: a constant chill chain and good hygiene in manufacture remain keys to maintaining the efficacy of the MAP process. Applying MAP to ready meals, in fact, presents considerable practical difficulties. Modified atmosphere packaging (MAP) combined with refrigerated storage is an efficient preservation method to extend the shelf life of fish products. The application of such "soft hurdles" reduces the rate of fish deterioration and spoilage caused by microbial growth. MAP offers many advantages to consumers and food producers. To the consumer, it offers convenient, high-quality food products with an extended shelf life. It also reduces and sometimes eliminates the need for chemical preservatives, leading to more "natural" and "healthy" products. At the same time, producers also enjoy the benefits of increased shelf life. By using MAP many products can be packaged centrally, and their distribution cost is reduced because fewer deliveries over longer distances become possible. Moreover, because of the extended shelf life, MAP allows transportation of foods to remote destinations and increases product markets. MAP also has several disadvantages. Usually, each MAP product needs a different gas formulation. This requires the use of specialized and expensive equipment. At the same time, production staff must receive special training. For most products, storage temperature control is required and product safety must be established. Furthermore, MAP causes larger package volumes, which leads to increased transportation and retail display space needs. All the above add a noticeable cost, which must be paid by the consumers. Finally, another disadvantage of MAP is that it loses all its benefits once the consumer opens the package.

3.0 Smart Packaging

Smart packaging provides a total packaging solution that on the one hand monitors changes in a product or its environment (intelligent) and on the other hand acts upon these changes (active). Smart packaging utilises chemical sensors or biosensors to monitor the quality and safety of food all the way from producers to consumers. As with the previously discussed technology, smart packaging utilises a variety of sensors for monitoring food quality and safety, for example by detecting and analysing freshness, pathogens, leakages, carbon dioxide, oxygen, pH level, time or temperature. The exact functionalities of specific smart packaging solutions vary and depend on the actual product being packaged, for example, food, beverages, pharmaceuticals, or various types of health and household products. Similarly, the exact condition to be monitored, conveyed, or adjusted vary accordingly. Smart packaging allows to track and trace a product throughout its lifecycle and to analyze and control the environment inside or outside the package to inform its manufacturer, retailer or consumer on the product's condition at any given time.

4.0 Active Packaging

Active packaging (AP) incorporates functional materials or additives that actively interact with the product and packaging environment to enhance food safety and quality while extending shelf life. O_2 scavengers and moisture absorbers are by far the most commercially important sub-categories of active packaging and the market has been growing steadily for the last ten years and is predicted to grow even further. All other active packaging technologies are also predicted to be used more in the future, particularly ethylene scavengers, CO_2 scavengers and emitters, and temperature control packaging.

O_2 Scavenger

An oxygen scavenger is a substance that reacts with oxygen chemically or enzymatically, thus protecting the packaged food against oxidative deterioration and quality changes due to oxygen. Most commercially available oxygen scavenging systems are based on the oxidation of iron powder or enzymes such as glucose oxidase, by oxygen present in the package's headspace. These reactions absorb most of the available oxygen in the package, minimize the interaction of oxygen with food, and thus prevent deterioration. Most often, oxygen scavengers are packed in a sachet highly permeable to oxygen and placed inside the package. Some safety concerns regarding the use of sachet-type oxygen scavenging systems in packaged foods are accidental ingestion of the sachet by consumers and potential spill/leak of the sachet contents into food. Careful research and development must be undertaken in selecting the appropriate sachet material and its seal integrity before commercial application, and appropriate warnings must be declared on the package.

CO_2-emitter

A CO_2-emitter is a device designed to release carbon dioxide (CO_2) within a controlled environment, particularly in the context of food packaging. The purpose of a CO_2-emitter is to enhance food preservation by increasing the concentration of carbon dioxide in the packaging. This technology is often employed in conjunction with modified atmosphere packaging (MAP), which involves adjusting the composition of gases surrounding the packaged product to extend its shelf life. The CO_2-emitter typically contains substances such as sodium bicarbonate interacting with ferrous carbonate or ascorbic acid, or a combination with sodium sulfite deoxidizer. These interactions result in the gradual release of CO_2, influencing the atmosphere within the packaging. The role of CO_2 in food preservation is multifaceted. It helps to reduce the respiration rate of fresh produce, slowing down the aging process, and inhibits the growth of bacteria in meat products. CO_2 achieves these effects by impacting cell membrane functions, altering the physicochemical properties of proteins, and hindering enzyme activities. The concentration of CO_2 released by such emitters is carefully controlled to create an environment that is conducive to food preservation. However, challenges such as the solubility of CO_2 in both water and oil, which can lead to the collapse of packaging, as well as the permeability of plastic films to carbon dioxide, necessitate ongoing advancements in packaging materials to ensure optimal gas content and ratios. CO_2-emitters play a crucial role in maintaining food quality and safety throughout the storage and transportation of various perishable goods.

Moisture Absorbers

Moisture absorbers play a crucial role in food packaging by helping to maintain the quality and freshness of products. These substances, commonly made of materials like silica gel or clay, are integrated into packaging to absorb excess moisture, which prevent the growth of mould, bacteria, and other microorganisms. Moisture can adversely affect the texture, taste, and shelf life of various food items, making the use of absorbers particularly important in products prone to moisture-related issues, such as dried fruits, grains, and snacks. By reducing humidity levels within the packaging, moisture absorbers contribute to the preservation of product integrity, preventing clumping, staleness, and microbial spoilage. This not only enhances the overall consumer experience by ensuring the product's sensory attributes but also extends the shelf life of packaged goods.

Antimicrobial Packaging

Antimicrobial active packaging represents a cutting-edge solution in the realm of food packaging technology. With the incorporation of antimicrobial agents like silver nanoparticles, essential oils, and enzymes, this packaging strategy aims to combat microbial growth on the surface of packaged goods. The utilization of silver nanoparticles, for instance, leverages the well-known antimicrobial properties of silver to inhibit the proliferation of bacteria and other microorganisms. Similarly, essential oils, such as those derived from oregano and thyme, bring natural antimicrobial benefits that can be harnessed when encapsulated within packaging materials. These innovations contribute to an extended shelf life for products by minimizing the risk of spoilage and enhancing overall food safety. Beyond shelf life extension, antimicrobial active packaging plays a pivotal role in reducing food waste. By creating a protective shield against harmful microbes, this packaging technology ensures that products remain fresh for a more extended period, reducing the likelihood of premature spoilage. Additionally, the enhanced safety and preservation of product quality are noteworthy advantages. This technology aligns with the broader goals of the food industry to deliver safe, high-quality products to consumers while addressing sustainability considerations and minimizing the environmental impact associated with food waste.

Antioxidant Packaging

Antioxidant packaging is a specialized form of packaging designed to protect products from oxidative reactions that can degrade their quality. Oxidation, driven by exposure to oxygen in the air, can lead to the deterioration of certain products, such as food items and pharmaceuticals. Antioxidant packaging incorporates materials or additives that help mitigate the impact of oxidation, preserving the freshness and integrity of the packaged contents. Commonly used antioxidants in packaging include natural compounds like vitamin C (ascorbic acid) and vitamin E (tocopherol), as well as synthetic antioxidants such as butylated hydroxy anisole (BHA) and butylated hydroxy toluene (BHT). These antioxidants function by scavenging free radicals and inhibiting the oxidation process. Antioxidant packaging is particularly valuable for products vulnerable to oxidation, such as oils, fatty foods, and pharmaceuticals containing sensitive active ingredients. The benefits of antioxidant packaging extend beyond preserving product quality. They contribute to extension of shelf life, reduction of food waste and maintains the nutritional value of the packaged items.

Active packaging systems with dual functionality

Active packaging systems with dual functionality represent an advanced strategy for enhancing the stability of packaged goods. Combining oxygen scavengers with carbon dioxide and/or antibacterial/antioxidant releasing systems offers a comprehensive approach to extending shelf life. The use of an oxygen scavenger alone may create a partial vacuum, risking the collapse of flexible packaging. Additionally, flushing a package with a gaseous mixture containing carbon dioxide can lead to CO_2 permeation through the packaging film, impacting product quality. To address these challenges, self-working devices that absorb oxygen and generate sufficient carbon dioxide are promising, especially for items like fishery products, where preventing microbial growth and maintaining optimal storage conditions are critical for prolonged shelf life and product freshness.

5.0 Intelligent Packaging

Intelligent packaging is a new packaging technology that integrates intelligent functions with conventional packaging systems. Intelligent packaging can sense, detect and record external or internal changes of products, further to provide food quality and safety information, and therefore extending the information function of packaging. Intelligent packaging is a revolutionary concept that goes beyond traditional forms of packaging by incorporating smart technologies to provide real-time information about the condition and quality of the packaged product. These systems utilize sensors, indicators, or RFID technology to monitor factors such as temperature, humidity, and freshness. The collected data can be relayed to consumers or stakeholders, enabling informed decisions about product safety and quality. Intelligent packaging is particularly valuable in the food and pharmaceutical industries, where maintaining specific storage conditions is crucial. This technology not only enhances transparency in the supply chain but also contributes to reducing waste by helping consumers make more informed choices based on the real-time status of the packaged goods.

Time-temperature indicators

Time-temperature indicators (TTIs) are innovative devices incorporated into packaging to monitor and communicate the cumulative exposure of a product to temperature over time. These indicators are crucial in industries such as food and pharmaceuticals where maintaining a specific temperature range is vital for product safety and quality. TTIs work by employing chemical or physical mechanisms that react to temperature changes, providing a visual indication of the duration and extent of temperature exposure. This visual signal helps both consumers and stakeholders to assess whether a product has been subjected to undesirable temperature conditions during storage or transportation. Time-temperature indicators play a pivotal role in enhancing transparency along the supply chain, allowing for informed decisions regarding the suitability of a product for consumption or use based on its temperature history.

Freshness indicators

Freshness indicator (FI) is an indispensable part of intelligent packaging, mainly including two types: indicator card (label) and indicator film. The colour changes of FI caused by the characteristic volatile from food can directly reflect the freshness of food. FI can provide qualitative or semi-quantitative information about food quality changes caused by physiological changes or microbial growth without destroying food packaging, and therefore can help consumers intuitively and scientifically judge food quality. FI is very suitable for non-destructive testing of freshness of perishable foods such as meat products, seafood, dairy products, fruits and vegetables. Although FI has such advantages, the applications of FI as a new intelligent packaging technology in the food industry are still rare.

6.0 Future Aspects

Smart packaging systems proved to be an effective mechanism to improve the food safety and shelf-life extension of the packaged foods. However, these technologies are in development stage in the seafood sector and thus needs ongoing researches and continued innovations to anticipate future advancement in food quality, safety and stability.