

Research Article

Active and Intelligent Packaging Systems-Application in Seafood

Mohan COA* and Ravishankar CN

Division of Fish Processing, Central Institute of Fisheries Technology, Cochin

Abstract

Seafood's being rich in easily digestible protein and polyunsaturated fatty acids are also highly perishable. Conventional method of packaging has limited functionality and are not interactive. Latest trend in packaging of food is the Smart packaging technology which improves the safety and shelf life of perishable commodities. Smart packaging involves a combination of specialized materials, science and technology to provide additional advantages over their traditional counterparts. Smart Packaging enhances packaging functionality through two methods: Active Packaging and Intelligent Packaging. Active Packaging enhances functionality, while Intelligent Packaging can communicate the packaged content's status, or communicate other messaging. The present article discusses the applications of smart packaging for seafood.

Keywords: Smart packaging; Active packaging; Intelligent packaging; Seafood; Freshness indicator

Introduction

The demand for good quality food product with improved quality and shelf life is on rise globally. Over the years, packaging have brought out a revolution in the marketing and distribution of food products including fish. Among the food categories, seafood ranks 3rd with respect to consumption which explains the importance of fish. Fish is a vital source of food for people. It is the most important single source of high-quality protein, providing approximately 16% of the animal protein consumed by the world's population (Food and Agriculture Organisation (FAO), United Nations, 1997). By any measure, fishes are among the world's most important natural resources. Fisheries production was 171 mmt in 2016 of which capture and culture fisheries accounted to 90.9 mmt and 80 mmt, respectively [1]. The total first sale value of fisheries was USD \$362 billion. Additionally, with over 25,000 known species, the biodiversity and ecological roles of fish are being increasingly recognized in aquatic conservation, ecosystem management, restoration and aquatic environmental regulation.

Like any other food commodities, fish is one of the highly perishable items which undergoes spoilage if sufficient care is not taken. Various preservation methods have been in place to overcome the spoilage of fish. Chilling and refrigeration is the most preferred preservation method as it helps in preserving fresh like quality. Chilling or icing is reducing the temperature of fish so as to prolong the lag phase of bacteria and helps in reducing the spoilage rate.

Fish being one of the most perishable foods, its freshness is rapidly lost even when stored under chilled conditions. Further, consumers demands to have fish in as fresh a state as possible so that the characteristics flavours are retained. Bulk transportation of fresh fish in ice has several limitations like limited extension of shelf life, unnecessary expenditure on freight due to ice, difficulty in handling and maintaining hygienic conditions due to leaching of ice melt water with leaching losses of soluble nutrients and flavouring compounds. Proper packaging will help in improving the keeping quality of fish. Packaging is an important aspect for improving the shelf life and marketability. Packaging enhances the consumer acceptability and hence saleability of the product. Traditionally, food packaging is meant for protection, communication, convenience and containment. The package is used to protect the product from the deteriorative effects of the external environmental conditionals like heat, light, presence or absence of moisture, pressure, microorganisms, and gaseous emissions and so on. Packaging is an integral part of the food processing and plays an important role in preventing or reducing the generation of waste in the supply of food. Packaging assists the preservation of the world's resources through the prevention of product spoilage and wastage, and by protecting products until they have performed their function. Basic requirements of a package are good marketing properties, reasonable price, and technical feasibility, utility for food contact, low environmental stress, and suitability for recycling. Simply packing fish is suitable packaging material will enhance the shelf life of chilled and refrigerated fish to 7 to 15 days depending on fish species [2-18]. However, in the normal packaging the spoilage process will be accelerated due to presence of O₂ in the normal air packing. Alteration in the package atmosphere will help in overcoming the problem of shelf life, which can be achieved by vacuum packaging or modified atmosphere packaging.

Vacuum Packaging

Important properties by which consumers judge fish and shell fish products are appearance, texture and flavour. Appearance, specifically colour, is an important quality attribute influencing the consumer's decision to purchase. In fresh red meat fishes, myoglobin can exist

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***Corresponding author:** Mohan COA, Division of Fish Processing, Central Institute of Fisheries Technology, Cochin, E-mail: comohan@gmail.com

in one of three chemical forms. Deoxymyoglobin, which is purple, is rapidly oxygenated to cherry red oxymyoglobin on exposure to air. Over time, oxymyoglobin is oxidised to metmyoglobin which results in a brown discoloration associated with a lack of freshness. Low oxygen concentrations favour oxidation of oxymyoglobin to metmyoglobin. Therefore, in order to minimize metmyoglobin formation in fresh red meats, oxygen must be excluded from the packaging environment to below 0.05% or present at saturating levels. Lipid oxidation is another major quality deteriorative process in muscle foods resulting in a variety of breakdown products which produce undesirable off-odours and flavours. Hence O_2 may cause off-flavours (e.g. rancidity as a result of lipid oxidation), colour changes (e.g. discolouration of pigments such as carotenoids, oxidation), nutrient losses (e.g. oxidation of vitamin E, β -carotene, ascorbic acid) and accelerates microbial spoilage thereby causing significant reduction in the shelf life of foods. Therefore, control of oxygen levels in food package is important to limit the rate of such deteriorative and spoilage reactions in foods. Oxygen level in the package can be controlled by using the vacuum packaging technique in which, the air present in the pack is completely evacuated by applying vacuum and then package is sealed. Vacuum packaging, which is also referred as skin packaging involves removal of air inside the pack completely and maintaining food material under vacuum conditions, so that oxygen available for the growth of microbes and oxidation will be limited. This will help in doubling the shelf life of fish under chilled conditions. This technique is particularly useful in fatty fishes, where the development of undesirable odour due to the oxidation of fat is the major problem. Vacuum packaging for chilled and refrigerated fishes doubles the shelf life compared to normal air packaging [3]. Application of this to frozen fishes is also commonly followed as it helps in reducing problem of freezer burn. This technique can be applied to fresh meat and fishes, processed meat and fishes, cheese, coffee, cut vegetables etc. One of the important aspect in the vacuum packaging is the use of packaging material with good barrier properties. Normally polyester-polyethylene or nylon-polyethylene laminates are used. Polyester and nylon provides good strength and acts as good barrier to oxygen. Polyethylene proves good heat sealing property and is resistant to water transmission. The advantages of vacuum packaging include reduction in fat oxidation, growth of aerobic microorganisms, reduction in evaporation thereby dryness and freezer burn in frozen products, extends shelf life and reduces volume for bulk packs containing lighter materials. Disadvantages include difficulty in use for sensitive crispy products and products with sharp edges, requires high barrier packaging material to maintain vacuum, creates anaerobic condition, which may trigger the growth and toxin production of *Clostridium botulinum* and the growth of *Listeria monocytogenes*. Additional barriers/hurdles are needed to control these microorganisms and also it is capital intensive. Alternative to vacuum packaging, reduced oxygen level in the package can be achieved by using active packaging system like oxygen scavenger. Use of oxygen scavenger is very effective in reducing the oxygen level to $<0.01\%$ within 24 h, which helps in preserving the quality of food [19]. This is not capital intensive and can be applied to any products including crispy and products with sharp edges.

Modified Atmosphere Packaging (MAP)

Marketing of Modified Atmosphere Packaging (MAP) foods have increased, as food manufacturers have attempted to meet consumer demands for fresh, refrigerated foods with extended shelf-life. It is also used widely, as a supplement to ice or refrigeration to delay spoilage

and extend the shelf life of fresh fishery products while maintaining a high-quality end product. A modified atmosphere can be defined as one that is created by altering the normal composition of air (78% nitrogen, 21% oxygen, 0.03% carbon dioxide and traces of noble gases) to provide an optimum atmosphere for increasing the storage length and quality of food/produce [20,21]. Oxygen, CO_2 , and N_2 , are most often used in MAP [21,22]. Other gases such as, nitrous and nitric oxides, sulphur dioxide, ethylene, chlorine [21], as well as ozone and propylene oxide [23] have been suggested for a variety of products and investigated experimentally. However, due to safety, regulatory and cost considerations, they have not been applied commercially. These gases are combined in three ways for use in modified atmospheres: inert blanketing using N_2 , semi-reactive blanketing using $CO_2:N_2$ or $O_2:CO_2:N_2$ or fully reactive blanketing using CO_2 or $CO_2:O_2$. Typical MAP machine and gas composition analyser is given in (Figure 1).

Development of modified atmosphere packaging

Kolbe was the first to investigate and discover the preservative effect of carbon dioxide on meat in 18th century and Coyne was the first to apply modified atmospheres to fishery products as early as 1930's. Modified Atmosphere Packaging (MAP) is the removal and/or replacement of the atmosphere surrounding the product before sealing in vapor-barrier materials. While technically different many forms of map are also case ready packaging, where meat is cut and packaged at a centralized location for transport to and display at a retail store. Most of the shelf life properties of meat are extended by use of map, but anoxic forms of MAP without carbon monoxide do not provide bloomed red meat color and MAP without oxygen may promote oxidation of lipids and pigments. Advances in plastic materials and equipment have propelled advances in MAP, but other technological and logistical considerations are needed for successful MAP systems for raw chilled fresh meat. The growth inhibition of microorganisms in MA is determined by the concentration of dissolved CO_2 in the product. The preservation effect of MAP is due to the drop in surface pH in MA products because of the acidic effect of dissolved CO_2 , but this could not entirely explain all of CO_2 's bacteriostatic effect. The possibility of intracellular accumulation of CO_2 would upset the normal physiological equilibrium by slowing down enzymatic processes. Thus, the effect of CO_2 on bacterial growth is complex and four mechanisms of CO_2 on micro-organisms has been identified [23-26]:

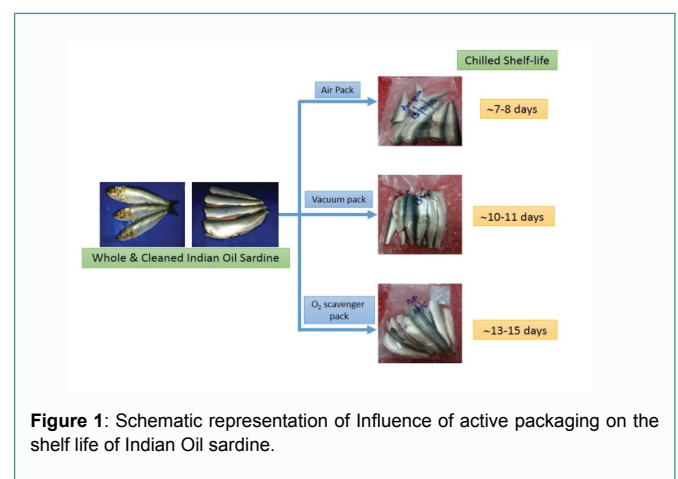


Figure 1: Schematic representation of Influence of active packaging on the shelf life of Indian Oil sardine.

1. Alteration of cell membrane functions including effects on nutrient uptake and absorption,
2. Direct inhibition of enzymes or decrease in the rate of enzyme reactions,
3. Penetration of bacterial membranes, leading to intracellular pH changes,
4. Direct changes in the physico-chemical properties of proteins.

Probably a combination of all these activities account for the bacteriostatic effect. A certain amount (depending on the foodstuff) of CO₂ has to dissolve into the product to inhibit bacterial growth. The ratio between the volume of gas and volume of food product (G/P ratio) should be usually 2:1 or 3:1 (gas:food product). This high G/P ratio is also necessary to prevent package collapse because of the CO₂ solubility in wet foods. The CO₂ solubility could also alter the food-water holding capacity and thus increase drip.

The major function of carbon dioxide in MAP is to inhibit growth of spoilage microbes. Carbon Dioxide (CO₂) is soluble in both water and lipid it has a bacteriostatic and fungistatic properties. Carbon dioxide lowers the intra and extra cellular pH of tissue including that of microorganisms. It affects the membrane potential and influence the equilibrium of decarboxylating enzymes of microorganisms. CO₂ increases the lag phase and a slower rate of growth of microbes during logarithmic phase. This bacteriostatic effect is influenced by the concentration of CO₂, the partial pressure of CO₂, volume of headspace gas, the type of micro organism, the age and load of the initial bacterial population, the microbial growth phase, the growth medium used, the storage temperature, acidity, water activity, and the type of the product being packaged. Pathogens like *Clostridium perfringens* and *Clostridium botulinum* are not affected by the presence of carbon dioxide and their growth is encouraged by anaerobic conditions. In general, carbon dioxide is most effective in foods where the normal spoilage organisms consist of aerobic, Gram negative psychrotropic bacteria. The CO₂ is flushed into the modified atmosphere package by evacuating the air and flushing the appropriate gas mixture into the package prior to sealing. Another method to create a modified atmosphere for a product is either to generate the CO₂ and/or remove O₂ inside the package after packaging or to dissolve the CO₂ into the product prior to packaging. Both methods can give appropriate packages with smaller gas/product ratio to the package. The solubility of CO₂ decreases with increasing temperature, hence MAP products should be stored at lower temperatures to get the maximum antimicrobial effect. Also the temperature fluctuations will usually eliminate the beneficial effects of CO₂. The rate of absorption of CO₂ depends on the moisture and fat content of the product. If product absorbs excess CO₂, the total volume inside the package will be reduced, giving a vacuum package look known as "pack collapse". Excess CO₂ absorption along with "pack collapse" results in the reduction of water holding capacity and further drip loss to the products.

The major function of oxygen is to avoid anaerobic condition which favours the growth and toxin production of *C. botulinum* and growth of *L. monocytogenes*. Oxygen in the MAP is also useful to maintain the muscle pigment myoglobin in its oxygenated form, oxymyoglobin. In fresh red meats, myoglobin can exist in one of three chemical forms. Deoxymyoglobin, which is purple, is rapidly oxygenated to cherry red oxymyoglobin on exposure to air. Over time, oxymyoglobin is oxidised to metmyoglobin which results in a

brown discoloration associated with a lack of freshness. Low oxygen concentrations favour oxidation of oxymyoglobin to metmyoglobin. Therefore, in order to minimize metmyoglobin formation in fresh red meats, oxygen must be excluded from the packaging environment to below 0.05% or present at saturating levels. High oxygen levels within MAP also promote oxidation of muscle lipids over time with deleterious effect on fresh meat colour. O₂ in MA-packages of fresh fish will also inhibit reduction of TMAO to TMA. Nitrogen (N₂) is an inert and tasteless gas, and is mostly used as a filler gas in MAP, either to reduce the proportions of the other gases or to maintain pack shape by preventing packaging collapse due to dissolution of CO₂ into the product. Nitrogen is used to prevent package collapse because of its low solubility in water and fat. Nitrogen is used to replace O₂ in packages to delay oxidative rancidity and to inhibit the growth of aerobic microorganisms. The exact combination to be used depends on many factors such as the type of the product, packaging materials and storage temperature. The gas ratio normally used are 60% CO₂ and 40% N₂, for fatty fishes and 40% CO₂, 30% O₂ and 30% N₂ for lean variety fishes. Shelf life of different fishes packed under vacuum and MAP at different storage conditions are given.

Smart packaging technologies

Traditional packaging concepts are limited in their ability to prolong the shelf-life of fish products. This can be overcome by adopting vacuum and modified atmosphere packaging technologies. However, these require capital investment apart from requirement of fresh food grade gas in case of MAP. This promoted the researchers to develop new and improved methods for maintaining food quality and for extending shelf life. Active and intelligent packaging, which are regarded as smart packaging technologies, is one such advanced packaging technique which is finding its way in the preservation of various food systems including fish and shellfish. The market for active and intelligent packaging systems are fast growing and their demand is projected to reach \$10.5 billion by 2021, fuelled by the development of new generations of products and more cost competitive prices, which will spur greater market acceptance for many product types.

Basis of smart packaging

Packaging has four basic functions, viz., containment, convenience, protection and communication. Conventional packaging systems offer limited protection and communicates only through the labelling. It will not provide any information about the quality and safety of the product. Active and intelligent packaging enhances the protection and communication functions, respectively. The following graphics explains how this enhanced functionality works.

Active Packaging

Active packaging is an innovative concept that can be defined as 'a type of packaging that changes the condition of the packaging and maintains these conditions throughout the storage period to extend shelf-life or to improve safety or sensory properties while maintaining the quality of packaged food' [27-29]. Active packaging (AP) performs some desired role other than providing an inert barrier between the product and external conditions and combines advances in food technology, bio-technology, packaging and material science, in an effort to comply with consumer demands for 'fresh like' products. This involves incorporation of certain additives into the packaging film or within packaging containers with the aim of maintaining and extending product shelf life. Active packaging technique is either scavenging or emitting systems added to emit (e.g., N₂, CO₂, ethanol, antimicrobials, antioxidants) and/or to remove (e.g., O₂, CO₂, odour,

ethylene) gases during packaging, storage and distribution. In case of a gas-scavenging or emitting system, reactive compounds are either contained in individual sachets or stickers associated to the packaging material or, more recently, directly incorporated into the packaging material. Major active packaging techniques are concerned with substances that absorb oxygen, ethylene, moisture, carbon dioxide, flavours/odours and those which release carbon dioxide, antimicrobial agents, antioxidants and flavours. The most important active packaging concepts for fishery products include O₂ scavenging, CO₂ emitters, moisture regulators, antimicrobial packaging concepts, antioxidant release are discussed here.

O₂-scavenger

Fish products are highly susceptible to oxygen as it leads to the growth of aerobic microorganisms and oxidation which causes undesirable colour changes (e.g. discolouration of pigments such as myoglobin, carotenoids), off-odours and flavours (e.g. rancidity as a result of lipid oxidation) and leads to loss of nutrients (e.g. oxidation of vitamin E, β-carotene, ascorbic acid) which adversely affects the quality. Therefore, control of oxygen levels in food package is important to limit the rate of such deteriorative and spoilage reactions in foods. Although O₂-sensitive foods can be packed appropriately using Modified Atmosphere Packaging (MAP) or vacuum packaging, these technologies do not always remove O₂ completely. Moreover, the O₂ that permeates through the packaging film cannot be removed by these techniques. By use of an O₂-scavenger, which absorbs the residual O₂ after packaging, quality changes of O₂-sensitive foods associated with low residual oxygen levels can be minimized. O₂ scavengers were first commercialized in the late 1970s by Japan's Mitsubishi Gas Chemical Company (Ageless[®]). O₂ scavengers are able to eliminate oxygen contained in the packaging headspace and in the product or permeating through the packaging material during storage. O₂ scavengers are efficient in preventing discolouration of fresh and cured fish, rancidity problems, mould spoilage of intermediate and high moisture products or oxidative flavour changes. O₂ scavenging concepts 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 (e.g. oleic or linolenic acid), rice extract or immobilized yeast on a solid substrate. Structurally, the oxygen scavenging component of a package can take the form of a sachet, label or film (incorporation of scavenging agent into the packaging film, which avoids the accidental consumption of sachet), card, closure liner or concentrate.

CO₂-emitter

The method of preserving food products using CO₂ is not new. Modified atmosphere packaging which mainly employs the gases like CO₂, N₂ and O₂ has been in use for extending the freshness of fish products since many decades. The high CO₂-levels (10% to 80%) are desirable for moist food products like fish, shellfish and meat products which inhibit surface microbial growth and thereby extend shelf-life. The overall effect of CO₂ is to increase both the lag phase and the generation time of spoilage microorganisms. Over the years this has been achieved by modified atmosphere packaging, in which a package is flushed with a mixture of gases including carbon dioxide at sufficient levels. However the concentration of CO₂ within the package will change due to the partial dissolution of CO₂ in to the product and permeability through the packaging film. Normally, the permeability of carbon dioxide is 3 to 5 times higher than that of oxygen in most plastic films, so it must be continuously produced to maintain the

desired concentration within the package. A carbon dioxide generating system can be viewed as a technique complimentary to MAP to overcome the drawbacks. The potential of CO₂ in MAP and more recently generation of CO₂ inside the packaging system have been explored in relation to a number of commodities for their successful preservation. Such systems are based on sodium bicarbonate, ferrous carbonate, ascorbate, citric acid etc. Sodium bicarbonate, when used together with ascorbic acid or citric acid in the presence of sufficient moisture generates CO₂. This technique is very simple and economical as it does not require any costly equipment and pure gases.

Moisture regulator

Wet food has a high vapour pressure, and hence the humidity in the food package increases. Apart from this a certain amount of moisture will be trapped in the packaging due to temperature fluctuations in high equilibrium relative humidity food packages or the drip of tissue fluid from cut fish and fish products. If it is not removed, this moisture will be absorbed by the product or condense on the surface, which cause microbial spoilage and/or low consumer appeal. An excessive level of water causes softening of dry crispy products. On the other hand, excessive water evaporation through the packaging material might result in desiccation of the packed foodstuffs. It may also favour rancidity of lipids. The controlling of this excess moisture in food package is important to lower the water activity of the product, thereby suppressing microbial growth and preventing foggy film formation. Apart from this, removal of drip from chilled fish and melting water from frozen fish and shellfish makes the package more attractive to the consumer. An effective way of controlling excess water accumulation in a food package is the use of high barrier film material with the appropriate water vapour permeability and use of moisture scavenger, such as silica gel, molecular sieves, natural clays, calcium oxide, calcium chloride and modified starch etc. Among these, silica gel is the most widely used desiccant because it is not toxic and non-corrosive. Drip-absorbent sheets for liquid water control in high raw foods such as fresh fish and shellfish basically consist of a super absorbent polymer in between two layers. Large sheets are also used for absorption of melted ice in packages of seafood during air transportation. The preferred polymers for absorbing water are polyacrylate salts and graft copolymers of starch. For dried fish applications, desiccants such as silica gel, molecular sieves, CaO and natural clays (e.g. montmorillonite) packed in sachets can be used.

Antimicrobial packaging

Major part of the fish spoilage is attributed to the microbial contamination and subsequent growth which reduces the shelf life of foods and increases the risk of food borne illness. Traditional methods of preserving fish from the effect of microbial growth include thermal processing, drying, freezing, refrigeration, irradiation, MAP and addition of antimicrobial agents or salts. However, some of these techniques cannot be applied to fresh fish products as they alter its fresh nature. Antimicrobial packaging is a fast developing active packaging especially for fish and meat products. Since microbial contamination of these products occurs primarily at the surface, due to post-processing handling the use of antimicrobials either by spray or dip treatment and more recently using antimicrobial packaging can be advantageous to improve safety and to delay spoilage. The principle action of antimicrobial films is based on the release of antimicrobial entities into the food which extends the lag phase and reduce the growth phase of microorganisms in order to prolong shelf life and to maintain product quality and safety. To confer antimicrobial activity,

antimicrobial agents may be coated, incorporated, immobilised or surface modified onto package materials. Promising active packaging systems are based on the incorporation of antimicrobial substances in food packaging materials in order to control undesirable growth of microorganisms on the surface of food. The antimicrobial compound embedded into the polymer acts by two different kinds of mechanisms. In the first method, the preservative is covalently immobilized into the polymer matrix and acts directly from the film when the food is brought in contact with the active material. Regarding the latter, the preservative is embedded into the matrix in the dry state. When the active material is brought in contact with a moist food or a liquid-like food, the preservative is released from the material and acts directly. In both cases the aim of the system is to extend the shelf life of the packaged foodstuff, inhibiting the microbial growth and preserving its properties. The classes of antimicrobials range from acid anhydride, alcohol, bacteriocins, chelators, enzymes, organic acids and polysaccharides. Apart from these, various plant derivatives and derivatives from fishery waste like chitosan can be incorporated into the packaging system as antimicrobials.

Antioxidant release

Antioxidants are widely used as food additives to improve oxidation stability of lipids and to prolong shelf-life, mainly for dried products and O₂-sensitive foods such as fishes as they contain highly unsaturated fatty acids. Antioxidants can also be incorporated into plastic films for polymer stabilization in order to protect the films from degradation. Incorporation of Butylated Hydroxytoluene (BHT) into the packaging film as an antioxidant is widely practiced. However, there has been some concern regarding the physiological effects of consuming BHT due to its tendency to accumulate in human adipose tissue. Hence, the use of synthetic antioxidants in contact with foods is decreasing. It is therefore desirable to use natural and harmless antioxidants. Vitamins E and C are the common natural antioxidants, and their incorporation in polymer films to exert antioxidative effects is still at the experimental stage. Vitamin E is stable under processing conditions and has an excellent solubility in polyolefins. Apart from these, natural antioxidants extracted from plant and animal substances and their use as antioxidant packaging is under experimental stages.

Active packaging systems with dual functionality

A more sophisticated way of extending the shelf life of packaged foods with active packaging systems is to use multiple function active systems. For example, the combination of oxygen scavengers with carbon dioxide and/or antimicrobial/antioxidant releasing systems significantly improves the storage stability of packaged foods. In the packages with O₂ scavenger alone, the removal of oxygen from the package creates a partial vacuum, which may result in the collapse of flexible packaging. Also, when a package is flushed with a mixture of gases including carbon dioxide, the carbon dioxide dissolves in the product creating a partial vacuum and certain amount of CO₂ permeates through the packaging film. But relatively high CO₂ levels are necessary in order to inhibit surface microbial growth and to extend the shelf life. In such cases, the self-working systems, which absorb O₂ and generate sufficient volume of CO₂ will be promising in extending the shelf life of foods particularly fishery products. ICAR-CIFT has developed the technologies for these active packaging systems to be adopted in different food systems to enhance the shelf-life.

Intelligent Packaging

Intelligent packaging senses some properties of the food it encloses or the environment in which it is kept and in form the manufacturer, retailer and consumer of the state of these properties. Although it is distinctly different from the active packaging concept, features of intelligent packaging can be used to check the effectiveness and integrity of active packaging systems. Intelligent packaging has been defined as 'packaging systems which monitor the condition of packaged foods to provide information about the quality of the packaged food during transport and storage'. Smart packaging devices, which may be an integral component or inherent property of a foodstuff's packaging, can be used to monitor a plethora of food pack attributes. A variety of indicators such as temperature, time-temperature, pack integrity, microbial growth, product authenticity and freshness are of interest to the fish packaging industry.

Time-temperature indicators

The basic idea behind this indicator is that the quality of food deteriorates more rapidly at higher temperature due to biochemical and microbial reactions. Operation of TTIs is based on mechanical, chemical, electrochemical, enzymatic or microbiological change usually expressed as a visible response in the form of a mechanical deformation, colour development or colour movement. The visible response thus gives a cumulative indication of the storage temperature to which the TTI has been exposed. Essentially TTIs are small tags or labels that keep track of time-temperature histories to which a perishable product like fish is exposed from the point of production/manufacture to the retail outlet or end-consumer. Their use in fish and shellfish products offers enormous potential where monitoring of the cold distribution chain, microbial safety and quality are of paramount importance. Hence, a Time-Temperature Indicator or Integrator (TTI) may be defined as a small measuring device that shows a time and temperature dependent, easily, accurately and precisely measurable irreversible change that reflects the full or partial temperature history of a food product to which it is attached.

Leakage indicator

The development of improved methods to determine food quality such as freshness, microbial spoilage, oxidative rancidity or oxygen and/or heat induced deterioration is extremely important to food manufacturers. In order to maximise the quality and safety of foodstuffs, prediction of shelf-life, based on standard quality control procedures is normally undertaken. Replacement of such time-consuming and expensive quality measurements with rapid, reliable and inexpensive alternatives has led to greater efforts being made to identify and measure chemical or physical indicators of food quality. Determination of indicator headspace gases provides a means by which the quality of a fish and meat product and the integrity of the packaging in which it is held can be established rapidly and inexpensively. One means of doing so is through the intelligent packaging incorporating gas sensor technology for sensing the oxygen and CO₂, as these two are the most commonly used gases. The monitoring of these gases in the package helps in establishing the food quality. The profiles of oxygen and carbon dioxide can change over time and are influenced by product type, respiration, packaging material, pack size, volume ratios, storage conditions, package integrity etc. A number of analytical techniques are available to monitor gas phases in MAP products. Instrumental techniques such as GC and GC/MS require breakage of package integrity and are time-consuming and

expensive. Portable headspace oxygen and/or carbon dioxide gas analysers use 'minimally destructive' techniques (packages can be re-sealed) but tend not to be applicable to real-time, on-line control of packaging processes or large scale usage. An optical sensor approach offers a realistic alternative to such conventional methods. They can be used as a leak indicator or to verify the efficiency of O₂-scavenger, CO₂ emitter or MAP systems. Most of these indicators assume a colour change as a result of a chemical or enzymatic reaction. The most common redox dye used for leak indicators is methylene blue.

Freshness indicators

An ideal indicator for the quality control of packaged food products should indicate the spoilage or lack of freshness of the product, in addition to temperature abuse or package leak. The information provided by intelligent packaging systems on the quality of food products may be either indirect (e.g. deviation from storage temperature and changes in packaging O₂/CO₂ concentration may imply quality deterioration through established correlation) or direct. These freshness indicators are based on the detection of volatile metabolites produced during ageing of foods, such as CO₂, diacetyl, amines, ammonia and hydrogen sulphide. Freshness indicators provide direct product quality information resulting from microbial growth or chemical changes within a food product. Microbiological quality may be determined through reactions between indicators included within the package and microbial growth metabolites. The chemical detection of spoilage of fish and the chemical changes in fish during storage provide the basis for which freshness indicators may be developed based on target metabolites. Total volatile nitrogenous compounds and biogenic amines such as histamine, putrescine, tyramine and cadaverine have been implicated as indicators of fish product decomposition. As the biogenic amines are toxic compounds and they cannot be detected sensorily, the development of effective amine indicators would be beneficial. Hydrogen sulphide, a breakdown product of cysteine, with intense off-flavours and low threshold levels is produced during the spoilage of fish and shellfish by a number of bacterial species. It forms a green pigment, sulphmyocin, when bound to myoglobin and this pigment can be used as a basis for the development of a freshness indicator in red meat fishes. Normally, the freshness indicators are incorporated into the packaging film, which reacts with volatile amines and other indicating agents produced during the storage of fish and other seafoods, and the freshness is indicated by a colour change.

Future prospects

Smart packaging systems contribute to the improvement of food safety and extend the shelf-life of the packaged foods. However these are evolving technologies in the seafood area and many of these systems are in the developmental stage. Continued innovations in active and intelligent packaging are expected to lead to further improvements in food quality, safety and stability.

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