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ADVANCEMENTS IN FRUIT PACKAGING TECHNOLOGY: A REVIEW

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ABSTRACT

Fresh Ideas: Advancements in Fruit Packaging Technology explores the forefront of innovation in preserving the freshness and quality of fruits while simultaneously addressing sustainability concerns. This abstract highlights the latest developments in fruit packaging, including the utilization of bio-based films derived from renewable sources like cellulose and starch. These films offer superior barrier properties against oxygen and moisture, extending the shelf life of fruits and reducing food waste. Additionally, active packaging systems have emerged as a promising solution, incorporating antimicrobial compounds and oxygen scavengers to inhibit microbial growth and delay ripening. Intelligent packaging technologies, equipped with sensors and indicators, provide real-time monitoring of fruit conditions, aiding in informed decision-making throughout the supply chain. Nanotechnology further enhances fruit packaging through the development of nanocomposites and nanosensors, improving barrier properties and enabling precise quality control. Moreover, the shift towards biodegradable materials such as biopolymers derived from corn starch and sugarcane bagasse presents a sustainable alternative to conventional plastics, reducing environmental impact. Despite these advancements, challenges such as cost-effectiveness and regulatory compliance persist, requiring collaborative efforts from researchers, industry stakeholders and policymakers. Fresh Ideas: Advancements in Fruit Packaging Technology paves the way for a more sustainable and efficient fruit packaging industry, ensuring that fruits reach consumers in optimal condition while minimizing environmental footprint.

Key words : Cellulose, Nanotechnology, Technologies, Plastics, Packaging, Environmental.

Introduction

A very important part of the food business is food packing, which protects food items from getting contaminated and keeps their quality. It is very important for keeping food safe, making it last longer and making shipping and marketing easier. Plastic, glass, metal, paper and cardboard are some of the materials that are used. The type of product, its shelf life, the amount of safety that is wanted and the way it is packaged all affect the choice of material.

First-level, second-level, and third-level food packing are the different kinds (Ishangulyyev, 2019). Primary packing includes things like cans, bottles, bags, and plates that come into direct touch with the food. Secondary packing, such as cardboard boxes, crates and shrink wrap, protects the item even more and makes it easier to handle and move. Tertiary packing is used to store and ship large amounts of goods. Information about the product, such as nutrition facts, chemicals and how to use it, can also be printed on food packages. It can also be used as a marketing tool to get people to buy your goods and set them apart from similar ones on the market. In the food business, sustainable packaging is becoming more popular as companies look for eco-friendly choices that cut down on trash, use of non-renewable resources, and the carbon footprint of their goods (Nicoletti, 2017). Bioplastics, reusable packaging and recovered materials are all examples of environmentally friendly packing materials.

On their way from farmer to fork, perishable produce relies heavily on their packaging. With the introduction of new materials and ideas, the trend of using over 1,500 distinct kinds of packaging in the US is expanding. While standardizing containers helps keep prices down, the industry has been shifting towards a larger variety of package sizes to meet the demands of retailers, consumers, food service purchasers, and processing facilities (Morone, 2016). The produce sector relies heavily on packing and packaging materials, so it's crucial that everyone involved—packers, shippers, buyers and consumers—has a good grasp of the many alternatives accessible to them. This fact sheet includes a rundown of typical industrial containers for produce, an explanation of the several kinds of packaging and information on their purposes, uses, and limits (Mohebi, 2015).

Ethylene and rate of respiration in fruits

Fruits are mostly examined for their nutritional content, firmness, flavour and texture. The quantity of ethylene in the fruit, as well as factors like temperature, oxygen level, variety, handling and rate of respiration, determine how long the fruit can be kept. Ripening fruits at lower storage temperatures might reduce their vulnerability to impact bruising. An essential component in fruit development, storage and maturation is ethylene, a naturally occurring ripening hormone (Slavin, 2012). Things like temperature, exposure length and focus all have a role. While strawberries are relatively low-rate yet very susceptible to ethylene, climacteric fruits such as mango, bananas and sapona are extremely sensitive. Even at quantities as low as 0.1 ppm, numerous commodities get damaged by ethylene, and there is no established threshold for this. Disease, degradation, physical harm and exposure to cold may all lead to an increase in ethylene production. The quality of fruit is greatly affected by ethylene-induced senescence (Kuswandi, 2017). Climacteric fruits are susceptible to ethylene-induced ripening, over ripening, and mealiness. The quick depletion of carbohydrate stores and water loss is also caused by the elevated respiration rates experienced by non-climacteric fruits. Fruits age and deteriorate mostly via respiration. Refrigeration and air ventilation facilitate the elimination of carbon dioxide, water and heat that result from the conversion of oxygen (Alam, 2020). Fermentation may occur in environments with inadequate ventilation due to the carbon dioxide gas generated during respiration. Increased carbon dioxide levels and oxygen deprivation might cause the fruit to die if confined in a container. When oxygen isn't present, chemical reactions lead to cell death, alcohol formation, and off-flavours that eventually rot the fruit. Rapid respiration may cause a significant loss of fruit since it is directly related to decay rate (Qin, 2018).

Recent advanced concepts of packaging

Fig. 1 : Apple packaging in boxes.

Fig. 2 : Fruits packaging.

To maintain the quality and safety of food items throughout their shelf life, food packaging is an essential part of today's food business. The four main purposes of conventional food packaging are security, confinement, promotion and ease of use. Food goods may be packaged in a variety of sizes and forms, which helps with logistics and allows brands to communicate with customers via logos and text (Alam, 2018). In response to customer preferences, they streamline the preparation of ready-to-eat meals or make them easier to handle. Plastic packaging has been extensively used by the food industry for over half a century because of its many benefits, including being cost-effective, practical, lightweight and adaptable. With 37% market share, they have supplanted more conventional materials used for food packaging, such as glass, metal, paper and cardboard (Prasad, 2018). Unfortunately, most materials are non-biodegradable and derived from petroleum, therefore their extensive usage has led to major environmental concerns on a global scale. The market is undergoing a transformation due to the introduction of new environmentally conscious packaging solutions. One viable option for preserving the environment and repurposing unused goods or industrial by-products is to use renewable and biodegradable materials (Handling of Fresh Fruits, 2020). The term “bioplastics” has recently come into use to describe a class of polymers that exhibit either biodegradability or biobased (partially or totally) composition. Products and materials are considered biodegradable if they can be broken down biologically into water, carbon dioxide, methane, basic elements, and biomass. Biobased products and materials are those that are generated from biomass.

Bioplastics are mainly categorized into three types: biobased but non-biodegradable, biodegradable but derived from fossil resources and a combination of the two. Biodegradable plastics are designed for organic recycling, while biobased polymers are often used as a replacement for petroleum-based alternatives. At the beginning of the cycle, crops may benefit from compost that was made from properly handled, separated and collected bio-waste (Watson, 2016).

Factors affecting freshness in fruits

Many creatures, including humans, rely on fruits for sustenance. Fruits are structures that form naturally on plants. Fruits may be broadly grouped into three types: simple, aggregate and multiple. In contrast to aggregation fruits, which originate from a single blooming fruit structure but have several ovaries, simple fruits only have one ovary and may have one or more seeds (Kader, 2020). Examples of fruits that are produced by a mixture of blooming structures are figs and pineapples. Climacteric and non-climacteric fruits are two more categories. While non-climacteric fruits do not ripen after picking, climacteric fruits may. When it comes to climacteric and succulent fruits, ethylene production and ripeness are the two most important factors in determining how fresh they are. On the other hand, non-climacteric and aggregate fruits are more affected by time, temperature, and deterioration indicators like colour and pH (Mahajan, 2014). The climatic conditions necessary for fruit production dictate the specific maturation phases that fruits go through. Ripeness is the developmental stage at which fruit is optimal for eating, whereas maturation is the process by which fruit undergoes chemical and physiological changes over its existence. This development stage is characterized by the attainment of the ideal amounts of fruity scent and taste, and it is typically characterized by physical qualities like colour and texture (Kuswandi, 2011). It is possible for fruits to ripen while still connected to the plant and for them to keep ripening after harvest. When a fruit reaches senescence, it has

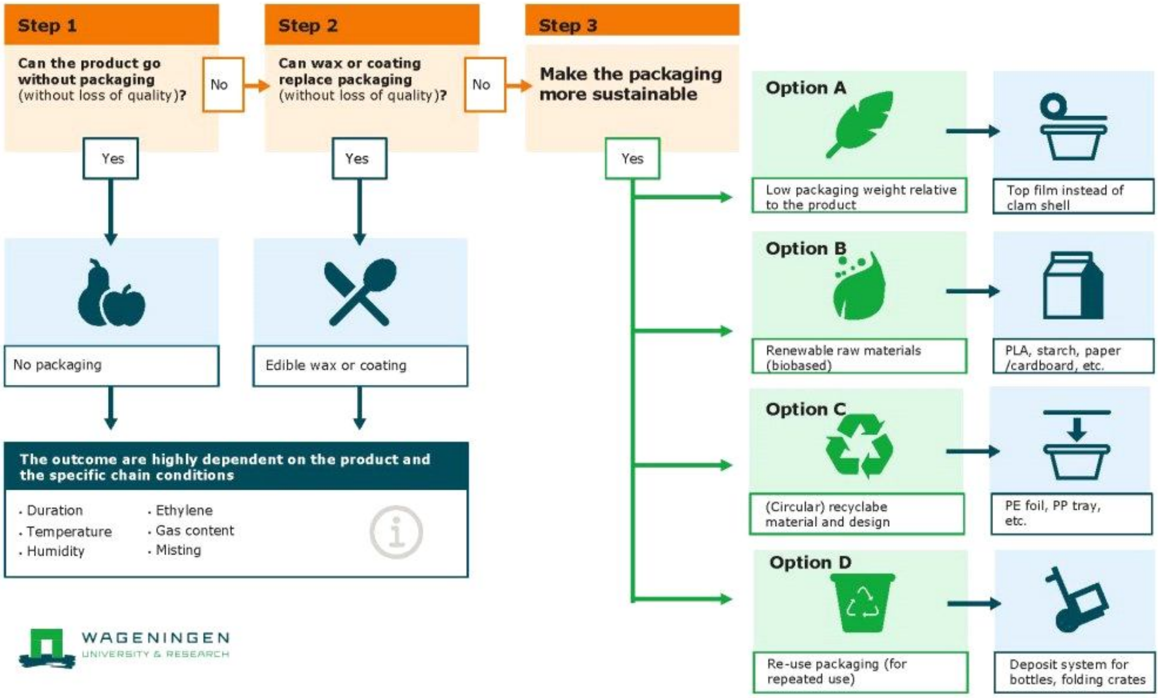

Fig. 3 : Ethylene work on fruits.

reached its maximum ripeness and is entering the irreversible degradation stages that will ultimately cause its death. At this point, the fruit's cells have begun to degrade and it no longer has many of its desirable qualities (El-Ramady, 2015). The release of several gases, including ethylene, is a hallmark of ripening, making senescence monitoring a useful indicator of fruit freshness. The quality of fruits is greatly affected by their processing steps, therefore it's important to use proper storage, shipping, and handling strategies to keep them fresh and prevent rotting. Fruits are picked and harvested as they reach ripeness. To guarantee the fruits are picked at the correct stage of ripeness, post-harvest processes are crucial. The optimal time to harvest fruit is determined by using maturity indicators, which might be visual, physical, or chemical in nature (Brodwin, 2020). You may also get a good idea of when to harvest based on calendar dates. To facilitate ripening during storage or transportation, the majority of fruits, particularly climacteric fruits, are picked before they reach full ripeness. Manual harvesting often yields higher-quality crops. After harvesting, the storage conditions are adjusted to maintain freshness with little deterioration. Overly high or too low of a storage temperature might hasten ripening by increasing transpiration and water loss. For every 10 degree Celsius rise, the temperature coefficient (Q10) quantifies the corresponding change in biological processes (Rickman, 2007). Fruit rots and decays more quickly in humid environments, whereas low humidity causes moisture loss. Managing the humidity and temperature of harvested fruits is a great technique to prevent them from ripening too quickly. Some external factors that may delay the aging process include edible coatings, calcium solutions, and chlorine solutions. While heat washing treatments or chlorine solutions kill microbes, calcium delays aging and slows their development on live fruit cells and tissues (Fuertes, 2016). The edible covering protects the fruit from harmful microbes by adding a waxy feel. The range, sensitivity, and lifespan evaluation of freshness sensors may be better understood with an understanding of fruit freshness criteria, which in turn assists in selecting the appropriate sensor for various fruit varieties. For better monitoring of fruit quality, understanding fruit physiology, development phases, and harvesting may help bridge the gap between freshness sensors and smart packaging sensors (Beshai, 2020).

Fig. 4 : Citrus peel advantages.

Importance of freshness in fruits

There are two primary categories of fruit packaging—consumer packaging and transportation packaging—both of which are essential to the distribution and sale of fruits. Fruits sold in bundles, each packed in its own plastic film or container, are known as consumer packaging. Produce in bulk may be transported in an organized, risk-free manner with the help of transport packaging (Kim, 2018). Protecting the contents from harm while accurately labelling their origin, grade, nutrition, etc. is the fundamental goal of both forms of packaging. Plastic containers are ideal for incorporating smart packaging sensors due to its chemical inertness, mechanical stability, and transparency. Many different varieties of fruit are available to shoppers, including fresh produce, frozen fruits without fat, and fruits in cans. While fruits retain more of their nutrients when frozen, the longer they stay in the freezer, the more likely they are to experience texture distortion, freezer burn, and nutritional loss compared to when they are picked (Vo, 2007). On the other side, fresh food is better for you since it has a shorter shelf life, tastes better and contains more nutrients. In order to ensure that consumers get fresh fruits that are safe, nutritious and of high quality, smart packaging is an absolute must. Industry leaders are increasingly motivated by the need for improved quality management and monitoring systems. Once a product has left the packaging facility, traditional commercial packaging cannot track its quality. Until the product is eaten, we can keep an eye on its quality thanks to smart packaging. Parts such as intelligent packaging, data processing and transmission and active packaging make up these subsystems (Mustafa, 2018).

Intellectual packaging is the part of smart packaging systems that uses sensors and indicators to measure the product's quality. The system as a whole relies on data transmission and management. There are a plethora of sensors on packages and they all work separately to either detect important data or show it. An external resource can interpret and analyse sensor data in real-time with certain smart packaging systems. Smart packaging not only keeps tabs on the things within, but it may also utilize active components to prevent products from spoiling, allowing for improved quality control (Boerman, 2016).

Modified Atmosphere Packaging (MAP) in fruits

In 1927, the concept of MAP (Material-Assisted Packaging) was first proposed as a way to increase the apple's storage life by exposing them to environments with reduced oxygen and increased carbon dioxide levels. First used as MA storage in the 1930s to preserve perishable goods like fruits and meat for long-distance shipping by increasing CO_2 concentrations, it has now been shown to extend store life by a factor of one hundred (Hu, 2012). Nonetheless, the technique was not made commercially available for retail packaging until the early 1970s in Europe. The primary technological limitation of MAP application in first trials was the lack of continuous regulation of package O_2 levels. Since then, there has been a proliferation of polymer types and properties, resulting in a wider range of options in terms of transparency, printability, flexibility, tensile strength, and gas permeability. This led to the development of MA packaging solutions for a wide range of products (Guo, 2007).

Product respiration and gas passage through packaging are two processes that naturally interact according to MAP principles, leading to an oxygen depletion and carbon dioxide enrichment environment. A variety of physiological changes are possible in this setting, including oxidation, degradation, changes in composition, softening, ripening, sensitivity to and generation of C_2H_4 and reduced respiration rates. What we call "MAP" stands for "multi-atmosphere packaging," which refers to the interaction between the product, the package and the outside air (Park, 2019).

One example of a commodity-generated MA is the polymer film used to wrap fresh food. Atmospheric modification is affected by the product's gas diffusion qualities, commodity respiration rate, film permeability, atmospheric composition inside the package, beginning free volume, surface area and weight. Airflow around the package, relative humidity and temperature all influence the film's permeability, which in turn impacts the commodity's metabolism and the pace at which it reaches the desired MA (De Almeida Teixeira, 2018).

The main goal of MAP is to quickly bring the CO and NO, levels within the package to an equilibrium as a result of interactions between the outside air, the package, and the product. Inadequately designed MAP systems may shorten the storage life of commodities or perhaps make them unusable. One method that has seen extensive usage in the processing and preservation of fruits and vegetables is MAP, or Micro-Aerobic Packaging. Because it slows metabolism and respiration, it extends the time that food ripens and ages, which is its primary benefit in terms of shelf life (De Almeida Teixeira, 2018). Chlorophyll retention, delayed softening and discolouration are all prevented by this. Produce also produces less water vapour waste when using MAP packs. Even when cut from their natural food sources and the plant itself, fresh produce keeps on breathing. The rate of carbon dioxide production or the rate of oxygen absorption under normal aerobic conditions are two ways to measure the rate of respiration. The concentration of both gases is considered to be in balance when the rate of product respiration is equal to the rate of CO_2 and O_2 transmission through the packing film. A product's respiration rate is affected by a number of factors, including its state of damage, its location, the kind of produce it is, and the temperature at which it is stored (Feng, 2010).

The present day sees the application of MAP technologies for both the long-term preservation of a wide range of fruits and vegetables and the retail sale of some sliced and chopped veggies. From agriculture to consumption, it enables the appropriate atmosphere to be maintained throughout post-harvest processing. Saving money, less labour and waste, better branding chances, more distribution areas and the chance of centralized or semi-centralized packaging are all benefits of MAP. In MAP, chemical preservatives are used sparingly, and the product is presented in a more aesthetically pleasing and legible manner throughout the packaging (Gómez, 2006). But MAP isn't without its flaws. Due to the inherent characteristic heterogeneity of the commodity and the film permeability, there is no universally accepted standard for MA packaging. Plastic films, if not recycled correctly, may be hazardous to the environment, yet MAP technology is not currently present in most goods. Inadequate packaging or excessive heat may cause products to degrade and the packing process will need more equipment and workers (Kuswandi, 2013).

Corrugated fiberboxes

The cheap cost and adaptability of corrugated fiberboard—also called cardboard or pasteboard—make it the dominating material for produce containers. The kraft process produces paperboard in many layers, with thickness and weight determining the grade. Kraft paper, which is produced from unbleached pulp, is known for its distinctive brown hue and remarkable strength. For added durability, it might use synthetic fibers, sizing (starch), and other components. The use of recycled fibers in fiber board is now commonplace and is only going to grow

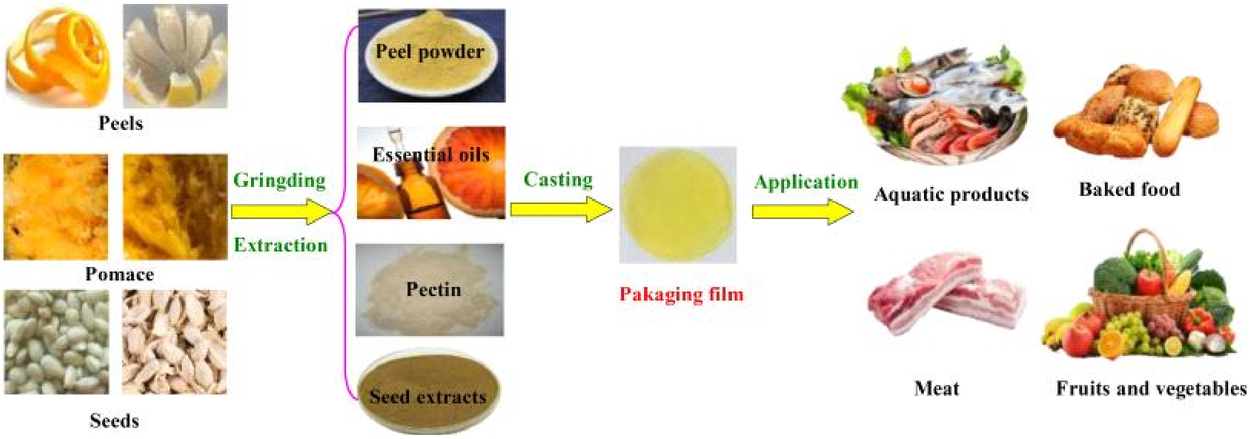

Fig. 5 : Post-harvest of citrus.

(Matindoust, 2015). Carton stacking strength is about 75% that of virgin fiber containers when made from completely recycled pulp, according to tests. Containers for fresh produce are most often made from double-faced corrugated fiber board, which consists of two layers of liner and corrugated paperboard. Double- or triple-wall construction is used for heavy-duty shipping containers, including corrugated bulk bins. The producers of corrugated fiber board confirm certain strength features and restrictions by printing box certifications on the underside of containers (Opara, 2019). The certification is based on either the minimum strength required to pass the edge crush test (ETC) or the minimum weight that the inner and outer facings must be combined to achieve. Each certificate specifies a maximum gross weight and maximum container size. The strength of fiber board containers is diminished at both low temperatures and high humidity. However, there are new coatings made of wax and plastic that may greatly mitigate the effects of moisture. Many product items that need hydro cooling or icing utilize waxed fiberboard containers, but disposing of them after usage is a big problem. Wax cartons have been subject to taxes or strict back haul laws by some states and cities as of late. According to sources in the industry, plastic or tightly regulated forced-air chilling systems will replace wax cartons for a lot of goods in the future (Fagundes, 2013).

Produce businesses often employ corrugated fiber board containers because to their high stacking strength, which is essential for preventing the crushing of perishable goods. The two-piece full telescoping container (FTC) and the one-piece regular slotted container (RSC) are the most popular styles of corrugated fiber board containers. The RSC's limited stacking strength necessitates the use of produce that can support part of the weight, but its simplicity and affordability make it popular. Conversely, the FTC is used in situations that call for increased stacking strength and bulge resistance (Beaudry, 2007). Designed for optimal stacking strength, the Bliss box is constructed from three individual pieces of corrugated fiber board. Glue, staples, or interlocking slots may be used to seal the tops and bottoms of all three kinds. Before being used, most corrugated fiber board containers are constructed at the packing house. This assembly may be done by hand, machine, or a mix of the two. Shipments of bulk food to processors and merchants have been increasingly made in recent years using big double-wall or triple-wall corrugated fiber board containers as one-way pallet bins. Some bulk containers may be collapsed and reused, and the cost per pound of product is as low as a quarter of typical size containers (Ageless Eye, 2020). Due to the high expense of materials and labour, the practice of printing labels on thick paper and attaching them to make packages has all but disappeared. The benefit of using corrugated fiber board containers is that they may have the brand, size and grade printed right on them. Post printing adds colour to the liner after the corrugated fiber board is produced, while pre-printing creates high-quality, full-color graphics; both procedures are often used to print on corrugated fiber board containers. The majority of corrugated fiber board container printing is done via postprinting, which often only allows for one or two colours and generates designs with less detail. Although market research indicates that exporters can gain from elaborate graphics, pre-printed boxes are usually reserved for new product or brand launches (Realini, 2014).

Oxygen scavengers

The proliferation of aerobic microbes, pungent doors, and colour changes are all symptoms of food spoiling, and oxygen plays a key role in this process. In order to keep food stable and extend its shelf life, it is essential to control the amount of oxygen in packaging. In order to lower the rates of oxygen penetration through container walls or to remove or decrease free oxygen levels, oxygen scavengers are engineered to oxidize food rapidly. The majority of oxygen scavengers work by combining various catalysts with food-grade water to create a hydrated metal reduction agent (Shillingford, 2016). This agent then sequesters oxygen and transforms it into a stable oxide inside the container. The packaging industry is, however, showing a growing interest in the research and development of non-metallic scavenging agents, such as photosensitive colorants that activate oxygen elimination when exposed to UV light, decreasing organic compounds, enzymes, microbes and yeasts. These systems work best with foods that are rich in water, but they need a trigger, such as Fe_2^+, Cu^+, or UV light (Ahvenainen, 2007).

Various biopolymer-based O_2 scavenger systems have been created, including edible films made of whey protein with ascorbic acid added, complexes involving ascorbyl palmitate and β-cyclodextrin, cast extruded PLA films with α-tocopherol microparticles, carboxymethyl cellulose films with α-tocopherol nanoparticles, fish gelatin films with α-tocopherol nanoparticles and $FeCl_2$, cationic nanofibrillated cellulose and polygalacturonic acid coatings, starch-based films with laccase and lignosulfonates and extruded thermoplastic starch films with ascorbic acid, iron powder and $CuCl_2$. Consumers are more receptive to these systems compared to the more conventional methods of packaging information, such as sachets or labels (Mills A. Oxygen indicators and intelligent inks for packaging food, 2005).

Carbon Dioxide (CO_2) Generators and Scavengers

To stop aerobic bacteria and fungi from growing in food, lower the oxygen content of certain items and stop flexible packaging from partially emptying because of oxygen scavengers or a drop in CO_2 concentration, CO_2 may be supplied to food packaging. But CO_2 at high levels may damage food products and their packaging. One example is a device that combines a liquid absorber and a CO_2 generating pad, which is enclosed in a bag or labelled as a CO_2 scavenger (Van Pelt, 2018). Another example is a device that contains dry powdered $NaHCO_3$ and citric acid. There have been reports of sachets and labels made of $FeCO_3$ or a combination of $NaHCO_3$ and ascorbic acid that may both generate CO_2 and scavenge O_2. There are currently no biodegradable or biobased polymer-based synthetic films on the market that can create CO_2, scavenge O_2, or do both. Plastics with a high permeability, as well as chemical and physical absorbers, may remove excess CO_2. Changes in moisture content may alter the physical sorption of CO, on the adsorbent (Mustafa, 2020). To control the amount of CO_2 and water absorbed and to create the ideal interior environment, films made of agar with sodium glycinate and/or sodium carbonate were created for use in packing perishable goods. For MAP, this gadget served as an insert label for shiitake mushrooms, creating the ideal environment for preserving their colour, firmness, taste, and bacterial development. To maximize the efficiency of CO_2 scavengers, it is necessary to understand the interplay between the food, packaging, absorber, and surrounding environment with regard to the production, dissolution, absorption and permeation of CO_2 (Mattila, 2009).

Ethylene scavengers

Even at low quantities, the phytohormone ethylene (C_2H_4) speeds up the respiration process in fruits and vegetables, making them riper, softer, and older than they otherwise would be. Delaying the ripening rate of climacteric fruit is essential for fresh fruit exports, and eliminating C_2H_4 from packaging helps with that. There are three ways to control CH_4 levels: using micro-perforated packing materials, reducing CH_4 concentration by mass spectrometry (MAP) by exchanging gases and removing ethylene using C_2H_4 scavengers or absorbers (Retama, 2016). The most prevalent compound that scavenges C_2H_4 is $KMnO_4$, which, when exposed to water, oxidizes C_2H_4 to CO_2 and H_2O. Available in sachets for storage and packaging, potassium permanganate is immobilized on inert matrices made with C_2H_4 highly permeable polymers. To wrap tomatoes and make them last longer in the fridge, Warsiki (2018) created chitosan films activated with $KMnO_4$. Nevertheless, $KMnO_4$ is too poisonous and has short-lived effects in humid conditions to be applied directly on food. The irreversible attachment of 1-methylcyclopropane (1-MCP) to the C_2H_4 receptor in fruit blocks C_2H_4 effects via competitive inhibition; this is one way to reduce C2H4’s effects (Ahuja, 2007). In commercial goods, it is contained in cyclodextrins and is released when the mixture is combined with water. Activated carbon, carbon impregnated with metal catalysts, or activated clays (zeolite, vermiculite and montmorillonite) packed in ethylene-permeable sachets or integrated into the packing film are all examples of active surfaces that may physically adsorb ethylene. Recent studies have developed chitosan films containing nanosized TiO_2. These films demonstrate C_2H_4 photodegradation into CO_2 and H_2O and they have the ability to prolong the storage life of cherry tomatoes at 25°C and 50% relative humidity by delaying ripening. Nanoclays are an additive to biodegradable and biobased polymers (Arshak and Adley, 2007).

Intelligent packaging

Sensing, monitoring, recording, tracing and providing information on food quality are all capabilities of intelligent packaging systems. You may use them to make judgments about quality, safety, and shelf life. There are primarily three types of intelligent packaging systems: indications, sensors, and data carriers. By reporting changes in the product or its surroundings, indicators provide rapid information about food via changes in colour or the spread of dye. To detect, identify, or quantify energy or matter, sensors give out detection signals or measure a physical or chemical characteristic that the gadget captures. They are able to identify food adulterants, allergies, contaminants, and pathogens down to the molecular level.

Particularly well-suited to large-scale operations like supply chains, data carriers are innovative gadgets that convey information or regulate the movement of goods. They are used for identifying, automating, tracking, preventing theft, or protecting against forgeries; nonetheless, they do not provide quantitative or qualitative information. Radio frequency identification (RFID) labels, bar codes and QR codes are the most crucial tools for the packaging sector.

Indicators of Freshness and Microbial Spoilage tell you how spoiled food has changed biochemically or how many microbes have grown on it. One way to tell whether food is still fresh is to look for quality indicators, which track concentration changes and often manifest as a change in colour response. The creation of certain metabolites, such n-butyrate, L-lactic acid, D-lactate, acetic acid, and volatile amines, causes a shift in pH, which is the basis for most indicators. New deterioration sensors for chicken, pig, and beef have been created by adding pH-sensitive materials to packaging.

In order to track the development of microorganisms in fish, Musso *et al*. (2016) created gelatin films that may change colour depending on the synthetic acid-base indicators used. Using a combination of methyl red and bromothymol blue, which changed colour from yellow-green to orange as the pepper decayed, Chen *et al*. (2018) created a freshness label for freshly cut green bell peppers.

When it comes to customer expectations about food safety, using natural pigments in biopolymers is the way to go. A solid partly polar adsorbent support that may change colour from colourless to violet when food pH changes was created by De La Puerta *et al*. (2014) and impregnated with a vanillin solution. For basic signals linked to food preservation, anthocyanins—flavonoids that give most fruits, vegetables, flowers and even certain cereal grains their vibrant colours—are a good possibility for pH-sensing labels that may be applied inside packaging.

To keep food from going bad and to keep its shelf life as long as possible, scientists have created a number of indicators. Indicators such as pH, natural substances, and synthetic colours are examples of such indicators. Red cabbage is a source of natural dyes that may react to changes in pH and change colour; these dyes are the basis for artificial colours. Other natural substances that may be utilized to detect changes in pH include betalains, which are pigments that contain nitrogen and are water-soluble.

Betalains come in two colours: red and yellow. They are nitrogen-containing pigments that are water-soluble. To keep an eye on how fresh chicken and fish were (Kanatt, 2020) created films out of gelatin and PVA that included Amaranthus leaf extract. For usage as food packaging pH indicator membranes, Moreira *et al*. (2018) created PLA/PEO ultrafine fibers containing phycocyanin.

It has been possible to monitor shifts in microbial development using package CO_2 indicators. The researchers (Morris *et al*., 2004) used agar and silicone sheets that contained a combination of bromothymol blue and methyl orange. As the pH drops because of the CO_2, the colour changes from green to orange. Another method for detecting CO_2 was to use chitosan or whey protein isolate in water; the transparency of these solutions varies with pH because CO_2 affects its appearance.

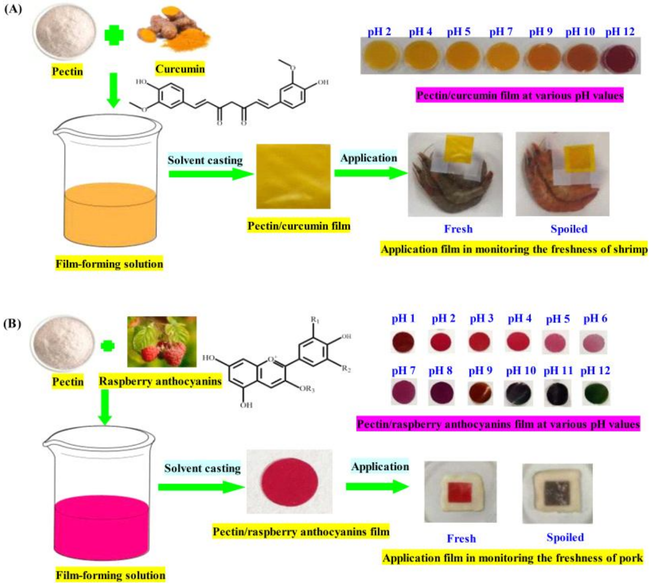

Fig. 6 : Different methods of packaging development.

As a consequence of trimethylamine N-oxide decomposition, vulnerable amines have been used as meat, poultry and seafood freshness indicators. Using

PET films coated with metalloporphyirin, Boscher *et al.* (2014) demonstrated the detection of trimethylamine, triethylamine, and dimethylamine. For modified-atmosphere poultry, Pacquit *et al.* (2006) and Smolander (2008) created a freshness indicator utilizing myoglobin immobilized in agarose.

It has been created to create fruit labels that may change colour to indicate various stages of ripeness. A lack of specificity and the possibility of false positives or negatives are two drawbacks that these indicators may have. Another method for detecting volatile amines is the use of electrochemical sensors. A pH-electrode passive sensor that displays basic volatile concentration was developed by Bhadra *et al.* (2015). It is covered with hydrogel.

Another significant aspect to consider when it comes to food rotting is humidity. An antimicrobial conductive nanocomposite film made of poly (sulfobetaine methacrylate) and bacterial nanocellulose was created by Vilela *et al.* (2019). This film can protect food from harmful UV rays, prevent the growth of harmful microorganisms that cause food poisoning and spoilage, absorb water and moisture and regulate the humidity levels in food using conductimetric sensors.

Keeping food items safe and delicious all the way through their lifecycle depends on their packaging being intact at all times. You may find gas indicators in packaging film or labels; they are widely utilized as integrity indicators for packaging applications. Microbe metabolism, permeation phenomena and chemical or enzymatic reactions in food are only a few examples of how these labels respond to changes in the packages inside environment. Colour changes caused by variations in gas composition might indicate improper package sealing, leakage, or manipulation.

Reports have been made for gas indicators for many gases, including O_2, CO_2, water vapour, hydrogen sulphide, ethanol and others. A rapid spoilage of the packed food may result from a leak in a container with a changed environment because of the dramatic rise in O_2 concentration and the corresponding fall in CO_2 concentration. The measurement of oxygen and carbon dioxide provides MAP with leakage indications. Colorimetric indicators based on a redox reaction, such methylene blue in an alkaline medium with a reducing agent like glucose are the most common O_2 indicators utilized. There are certain limits to these dyes, too, such as the fact that the colour shift becomes less noticeable when the O_2 level lowers (a reversible occurrence). Put oxygen scavengers and O_2 indicators in the same container to sidestep this issue.

The ink used to activate oxygen sensors visually is made up of the following components: hydroxyethyl cellulose, an electron donor called triethanolamine, a redox dye called methylene blue, and a semiconductor called TiO_2. A blue film showing oxygen content may be produced by coating or printing these indicators on different surfaces; when activated by UV light, the film turns colourless.

A large-scale oxygen indicator that is triggered by UV light and based on a colorimetric shift was recently created by Saarinen *et al.* (2017). An O_2 indicator was created by Vu and Won (2013). It activates when exposed to UV-light and may return to its normal colour when oxygen is present. To physically isolate the O_2 indicator's components, Jang and Won (2014) suggested a pressure-activated O_2 indicator.

It is also possible to detect CO_2 in food packaging using oxygen sensors that rely on phosphorescence. Excitation and detection of these luminous dyes, however, need high-tech apparatus. In conclusion, oxidative enzyme-based O_2 detection devices may be prepared in pill form, printed in layers, or laminated in a polymeric film.

Products with a limited shelf life may be better monitored with the use of Time-Temperature Indicators (TTIs), which track the temperature of these items over time and provide warnings when they may have begun to spoil due to microbial growth or protein denaturation. Because TTIs rely on permanent colour changes, buyers can easily tell whether a product is safe to use. Signs of incomplete history, full history indicators, and crucial temperature indicators are the three types of TTIs. The chemical, electrochemical, mechanical, enzymatic, or microbiological indicators often exhibit observable reactions, such as changes in colour or mechanical deformations, to convey their measured values.

There are TTIs that can be used to regulate the quality of fresh chilled pork, indicate the quality of ground pig patties, and use total plate counts to assess the quality of turbot sashimi. Other applications include monitoring the quality of vacuum-packed chicken breasts to detect any changes that may occur during storage. Using gold nanoparticles generated in situ in alginate, researchers have created a plasmonic thermal history indicator. The indication becomes red after prolonged exposure to high temperatures and gets more intense with higher storage temperatures and duration.

Specialized dynamic inks called thermochromic inks change colour when heated or cooled. They show when there has been thermal abuse and when things are comfortable. Unless subjected to a certain temperature, irreversible TTIs remain colourless. In contrast, reversible TTIs may change colour when heated and then go back to their original hue when the temperature drops. For example, if a refrigerated product's cold chain is broken, an irreversible TTI would indicate that the product's storage temperature was higher than the recommended value.

Irreversible thermochromic inks used in model food compositions were the subject of recent patents issued to articles and methods for detecting heating patterns (Watts and Liu, 2019). Over a predetermined temperature range, these inks may display a temperature-dependent variation in at least one colour characteristic.

Biosensors

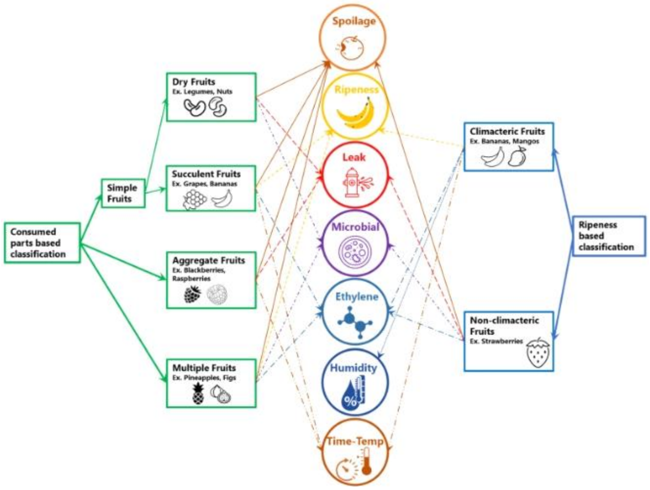

Fig. 7 : Fruits and packaging.

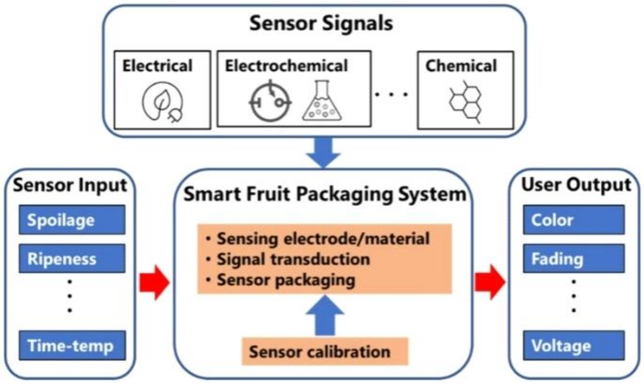

Fig. 8 : Smart packaging.

The use of biosensors in food packaging allows for the detection, registration, and transmission of information on biological reactions. They have the power to regulate product freshness, cut down on food waste, and lessen the likelihood of food poisoning. The bio-receptors in biosensors identify the target analyte, while the transducers convert the biochemical signals into a measurable electrical response. One system that uses a particular antibody attached to a bar code's membrane to identify food-borne diseases is the Food Sentinel System (SIRA Technologies Inc.). Commercially available, Toxin Guard® is a visual diagnostic that may identify harmful microbes by displaying antibodies imprinted on a polyethylene polymer.

The development of new and improved nanobiosensors for the detection of infections, chemical pollutants, spoilage, product handling and processing follow-up has been a game-changer in this area of action, made possible by nanotechnology. Colorimetric sensors can detect chemical vapours and change colour when volatile components react with chemical colorants, allowing for non-destructive examination of food scent. In order to detect the condition of packed goods and signal when they have reached the end of their usable life, Chen *et al*. (2017a) converted a food barcode into a colorimetric sensor that was integrated with a camera.

To determine whether fish is fresh, look for the freshness markers hypoxanthine and trimethylamine oxide. There has been research on xanthine oxidase-based enzymatic biosensors that use colorimetric or electrochemical reactions. While, Chen *et al*. (2017b) created a multicolour sensor for hypoxanthine detection using gold nanorods, Yan *et al*. (2017) described a colorimetric sensor for xanthine detection that used a copper nanocluster with peroxidase-like activity. A colorimetric method for the detection of trimethylamine oxide was developed by Schaude *et al*. (2017). It relies on pH indicator dyes that are immobilized on cellulose microparticles and embedded in food-grade silicone.

Because of their mobility and capacity to detect in real time, biosensors show great promise as a means of identifying harmful microbes. But most biosensors rely on DNA or immunological detection, which requires specific facilities, labels and time. To circumvent these issues, synthetic antimicrobial peptides have been advanced as a viable option due to their great stability, large-scale producibility and low cost.

To identify Listeria monocytogenes in meat and milk samples, scientists have created colorimetric biosensor strips using immobilized peptides. The translucent cyclo-olefin polymer packaging contains samples of meat and apple juice and a fluorescent DNAzyme probe was printed on it not long ago.

A number of portable microfluidic devices, including bright-field imaging, lateral-flow strip tests and other similar technologies have been created specifically for the purpose of detecting bacteria. These sensors may be embedded into food packaging and enable for real-time electrochemical detection of bacterial accumulation.

Many biosensors have their origins in the ability to detect gases inside packages. New optical O_2 sensors using microstructure pillar detection layer arrays have been produced, and optical fiber O_2 sensors based on luminescence have been manufactured using layer-by-layer Nano assembly methods. Another possible solution to the problems of microbiological fouling and dye leaching is the use of mesoporous materials, which might increase sensitivity.

One promising use of CO_2 sensors is the detection of food deterioration using optochemical methods that combine a phosphorescent dye with a colorimetric pH indicator. While there are a number of CO_2 detectors available, they are bulky, costly, and easily contaminated by water vapour and other contaminants.

A number of scientists have created squaraine-based systems that can detect CO_2 gas in dimethyl sulfoxide (DMSO) with high sensitivity and colorimetric and fluorescent capabilities. They have also created squaraine-based chemosensors that can detect CO_2 gas with proton nuclear magnetic resonance and UV-visible spectroscopies in DMSO, as well as a cationic chemosensor that can detect the change with the naked eye and is very sensitive.

Radiofrequency Identification (RFID)

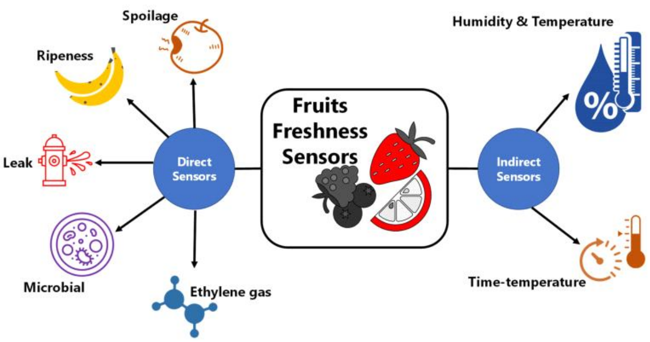

Fig. 9 : Principles of packaging.

For the purpose of product tracking and identification, radiofrequency identification tags may store and transmit data in real time. An antenna transmits data contained on the chip to a reader, which is comprised of an integrated circuit. The power needs of an RFID system dictate whether, it is active or passive. Both low- and high-frequency applications use them in food packaging. The primary goals of radio frequency identification (RFID) technology are to receive radio frequency energy from an interrogator, activate the tag's RFID chip and then communicate an identifying code back to the interrogator.

The reader acts as a platform that receives data from the tag and processes it for further analysis. The Electronic Product Code is a series of bits encoded on an electronic chip. Filtering, data integration, reader synchronization, and correct scheduling are just a few of the many tasks carried out by RFID middleware.

With temperature and storage time being the two primary variables impacting food quality, RFID devices play a pivotal role in tracking and monitoring the food supply chain. Using radio frequency identification (RFID) on "bar codes" has several benefits, such as enabling unique product identification, remote control and simultaneous monitoring of many components. Several businesses produce RFID labels, which have found their way into expensive items like apparel and gadgets. These devices may be fastened to packaging in the food business, allowing for better monitoring and identification. Several RFID vendors have collaborated with the meat and fish sectors to deploy RFID systems, including EPSILIA of Canada, RFID Enabled Solutions Inc. of the United States, and HRAFN Ltd. of Sweden. The introduction of pH and humidity sensors, as well as CO_2 and O_2 sensors for maintaining the freshness of meat, vegetables, and dairy goods are examples of advancements in RFID systems.

Conclusion

In conclusion, the exploration of advancements in fruit packaging technology underscores a promising trajectory towards enhancing freshness, quality and sustainability in the fruit industry. Through the integration of bio-based films, active packaging systems, intelligent technologies, nanotechnology and biodegradable materials, significant strides have been made in addressing key challenges such as food waste and environmental impact. These innovations not only extend the shelf life of fruits but also contribute to reducing losses, improving efficiency, and meeting the evolving needs of consumers. However, to realize the full potential of these advancements, collaborative efforts are imperative to overcome remaining hurdles such as cost-effectiveness and regulatory compliance. By fostering continued research, industry collaboration, and policy support, the fruit packaging sector can further accelerate its transition towards more sustainable and efficient practices. Fresh Ideas: Advancements in Fruit Packaging Technology serves as a beacon for the industry, signaling a future where fruits are not only fresher and of higher quality, but also packaged in a manner that is environmentally responsible and economically viable.

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