**Modern and Traditional Food Preservation and Packaging Technologies: Principles, Applications, and Implications**

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**ABSTRACT**

Food contamination can occur from harvesting from farms to food plates. More than 200 illnesses can occur because of eating contaminated food. Food storage and packaging techniques are needed for various reasons because they contribute to extending the shelf life of delicate food items, lowering the possibility of decomposition, and minimising food waste. While current technology has offered creative packaging and preservation solutions, old approaches, influenced by cultural and historical aspects, continue to be used, and those techniques are not very effective .Nowadays consumers require advanced techniques that will not compromise the quality of food. To meet this need, modern preservation and smart packaging have been developed. This chapter examines the concepts, principles and applications, of modern and traditional food preservation and packaging methods in the food sector. This chapter examines the essential characteristics of both techniques, their advantages and disadvantages, as well as their influence on food preservation, sustainability, and customer preferences. This chapter examines the advantages and disadvantages of modern and conventional food storage and packaging technologies in an effort to provide industry professionals, academics, and policymakers with important insights.

Keywords: Food preservation, Food packaging ,Smart packaging, Active packaging

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**1. Introduction:**

Food storage and packaging technologies are particularly vital for assuring our food safe, fresh, and lasting longer (Ahmed *et al.,* 2017). As the world's population continues expanding, it's highly crucial to develop excellent methods to conserve food and prevent waste (Salemdeeb *et al.,* 2017). This chapter explains about why food storage and packaging technologies are so essential, and how they have developed through time. It seeks to assist readers grasp the fundamentals, uses, benefits, and downsides of both ancient and modern approaches.

**1.1 Food storage and packaging**

Food storage and packaging solutions are important for a number of reasons. They aid in improving the shelf life of sensitive food goods, lowering the danger of deterioration and minimising food waste (Ghaani *et al*., 2016). Secondly, these technologies help with the preservation of food quality and nutritional content, ensuring that customers obtain safe and nutritious food. Furthermore, effective storage and packaging methods improve food convenience and accessibility, making it simpler to carry, ship, and consume (Han *et al.,* 2018). Further, food storage and packaging technologies contribute to environmental sustainability by minimising waste and optimising the utilisation of resources (de los Mozos *et al*., 2020)

The evolution of food storage and packaging technologies can be traced back to traditional methods that have been practised for centuries. Traditional approaches include techniques such as root cellars, drying, fermentation, canning, and smoking. These methods relied on natural processes and materials available locally (Amit *et al.,* 2017b). Modern techniques, developed when science and technology advanced. Active packaging technologies, intelligent packaging systems, and environmentally friendly packaging materials have transformed the industry. These modern methods make use of advancements like modified atmosphere packaging (MAP), smart sensors, biodegradable packaging, and others (Ghaani *et al.,* 2016).

The objectives of this chapter are to investigate the concepts underlying present food storage and packaging methods and compare them to previous ways. It intends to investigate their uses in perishable and non-perishable foods, fresh produce, meat, dairy, drinks, bread items, and confectionery. The chapter will also cover the advantages and disadvantages of both modern and traditional approaches, such as shelf-life extension, food safety, convenience, sustainability, cost-effectiveness, and cultural importance. Finally, it will evaluate the consequences and future directions of food storage and packaging technologies, taking into account hybrid methods, consumer education, industrial concerns, and government.

By learning about the principles and applications of modern and traditional food storage and packaging technologies, industry professionals, policymakers, and consumers can make sensible choices and embrace a holistic approach to ensuring the safety, quality, and sustainability of our food supply chain.

**2. Principle of traditional food preservation technologies**

**2.1 Root Cellars and Cold Storage**

Food preservation has been an important practice throughout human history since it provides for the storage and availability of food when fresh product is limited. Traditional food preservation technologies, such as root cellars and cold storage, have been crucial in this process (Kale *et al.,* 2016) Root cellars and cold storage have been utilised for centuries to increase the shelf life of perishable commodities such as fruits and vegetables .

Root cellars are underground constructions that provide cold, damp conditions ideal for the storage of fruits, vegetables, and root crops. Root cellars are not a new notion; they have been utilised as a technique of food preservation for centuries. Root cellars are not a new thought; they have been exploited as a way of food preservation for millennia .

They offer cold and humid conditions, which assist to increase the store lifespan of fruit, vegetables, and root crops. One study conducted by researchers focused on assessing the effect of multiple variables on the efficiency of food preservation in root cellars.The findings revealed that temperature, humidity levels, ventilation, and insulation were significant elements determining the effectiveness of food preservation in these subterranean buildings. These findings suggest that proper construction and maintenance of root cellars is essential for effective food preservation. In addition to root cellars, cold storage has also been extensively employed as a traditional technique of food preservation (Özogul & Hamed, 2018). Cold storage is the use of low temperatures to slow down the spoiling process and protect the quality of perishable items. Both root cellars and cold storage have been exploited since ancient times, proving their long-standing importance in food preservation (Slaney, 2020)

While root cellars and cold storage are historic means of food preservation, their concepts and applications have endured across time. Today, we still use improved and altered versions of these ideas to preserve food. Modern technologies, such as cooling and freezing, have replaced the need for underground root cellars in numerous regions of the world. However, root cellars continue to be utilised in certain areas where availability of modern refrigeration is constrained. Additionally, cold storage is frequently employed in many different areas of the food industry, notably farming, fishing, and food processing.(Slaney, 2020) Root cellars and cold methods of storage are beneficial in improving the shelf life of vegetables, fruit, and other perishable foods.

**2.2 Smoking, Curing and Salting**

Smoking is an efficient food preservation method that prolongs the storage life of products but also enhances their flavour, appearance, and mouthfeel (Alomirah *et al*., 2011). There are two fundamental techniques for food smoking: conventional and industrial. Additionally, smoke-generating technologies may be classified into many forms, such as fluid smoke, steaming smoke, friction smoke, electrostatic smoke, fluidization smoke, decomposing smoke, and contact smoke (Ledesma *et al*., 2017).

In the construction of smoked meat-based dishes, the most often utilised smoking technologies are conventional smouldering smoke and industrialised smouldering smoke. The conventional method is to ignite timber right away below the hung flesh in a smokehouse for a long time, needing competent operators to regulate humidity, temperature, and combustion density by changing the amount of moisture of the chipped wood or saw dust as well as controlling the smokehouse's ventilation (Yin *et al.,* 2021).

Industrial manufacturing of smoke meat products, on the other hand, necessitates an automated smokehouse. Wood particles or sawdust are mechanically delivered into an ignited bed in smouldering-type engines, providing more accurate haze creation under regulated circumstances. This industrial procedure is useful as it lowers the development of potentially dangerous elements, such as polycyclic aromatic hydrocarbons (PAHs), by enabling char granules to settle during smoke passage through the pipe system (Alomirah *et al*., 2011). Smoking has historically been applied to increase the preserving impact of foods during curing, but owing to the flavour supplied to food, it has acquired widespread acceptance.

Curing is a technique for meat, vegetables, and seafood to reduce moisture content through the osmosis dehydration method (Amit *et al.,* 2017b). The osmotic dehydration procedure reduces the moisture content of foods like fruits and vegetables, reducing microbial damage (Gómez *et al.*, 2020). Curing also improves the flavour of the goods. The primary purpose of adding salt to vegetables, meat and seafood was to preserve it. Nitrates, sugars, and nitrites were also added. Adding salt to food goods slows the oxidisation process, which aids in reducing rancidity (Pegg & Honikel *et al,* 2014*)*.

Sodium chloride serves several purposes in food preservation and production. It extends the duration of storage of cured food by decreasing the fluid content of the food, which reduces the microbial load (Durack *et al.*, 2008). Salt is important in influencing the gelation, emulsification, and linking characteristics of meat muscle proteins (Jeanette *et al.,* 2021).

Cold storage is a critical component of the agricultural supply chain. Generate degrades rapidly in the absence of timely chilling and a suitable storage environment. Nutritional losses are possible, as can the decomposition of complete food products. Quick cooling to remove residual field temperature increases shelf life and overall quality (Ahmad et al., 2021).

**2.3 Canning**

Canned foods are not generally consumed by the populace in less developed countries, owing to their high cost, which renders them inaccessible to the typical customer. The high demand for water and energy throughout the canning process raises canning costs (Ahmad *et al.,* 2021; Featherstone *et al.*, 2015). Many types of tinned food are exported from developing countries to more affluent ones, with developing countries accounting for more than 25% of canned fruits and vegetables bought by European countries. This trade generates a substantial quantity of foreign cash for low-income countries, particularly canned fish, vegetables, and fruits (Ahmad *et al.*, 2021).

Canning is an important method of food preservation that involves several methods, including refrigeration and heating, to prevent the growth of microbes and enzymes in the food (Ahmad *et al.*, 2021; Joardder & Masud, 2019). To ensure safety, it is crucial to treat raw materials adequately, especially fish, which may contain harmful microorganisms like Clostridium botulinum that can be fatal. Achieving the best quality canned products involves proper heating conditions and the use of fresh, healthy ingredients. Fish and meat have a high number of primary microorganisms and internal water content, with a nearly neutral pH, making it challenging to create a safe-to-consume product. Continuous heat in a pressure steriliser at temperatures above 100 degrees Celsius is a free-of-risk method of effectively eliminating microorganisms (Ahmad et al., 2021; Tauxe *et al.,* 2001). For protein-rich foods, a hermetic sealing process is applied after heating, while plant-based foods do not require pre-heating before canning. To restrict microbial growth, canned products often contain vinegar, acetic acid, or oil (Featherstone *et al* 2015). The advantage of canned goods is their long shelf life without the need for refrigeration.

**2.4 Fermentation**

Microorganisms are utilised in the fermentation technique to preserve food. The carbohydrates are broken down in this process by microorganisms and enzymes (Amit *et al.*, 2017). Various microorganisms, such as yeast, bacteria, and moulds, play a critical role in fermenting a broad diversity of food items such dairy products, cereal-based dishes, and meat products (Amit et al., 2017). Fermentation enhances the nutritional content, health benefits, and digestion of foods, giving an enhanced substitute to the use of harmful chemical preservatives (Kårlund *et al.*, 2020,Amit *et al*., 2017).

**2.5 Drying and dehydration**

Drying, referred to as dehydration, is a process of eliminating water from solid or liquid food by evaporation. The major objective of drying is to generate a solid product with minimal water content, which assists in the prevention of the development of microorganisms and enzymes that cause food rotting (Berk *et al.,* 2018). This technique of preserving has been practised for millennia and is highly efficient in inhibiting the destructive acts of these microorganisms, which need moisture to flourish. Drying provides several advantages, including decreasing food volume and weight and enabling it easier to keep, package, and transport. It may also boost the tastes and smells of various meals, making them more enticing to consumers.

However, it is vital to know that drying has certain downsides. In rare instances, the technique could cause substantial taste and scent loss, making the food less appetising. Important nutrients including vitamin C, thiamine, fat and protein, may also be damaged during the drying process (Amit *et al.*, 2017).

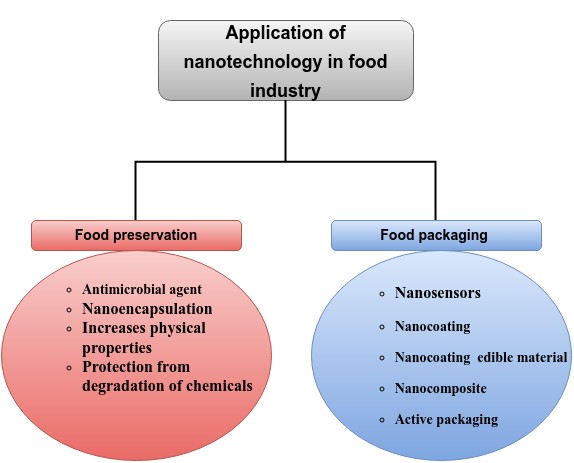
There are numerous sorts of drying technologies, such as convective, conductive, and radiative drying. Convective drying is the most prevalent procedure used to produce > 90% dehydration in foods. Depending on the individual demands, dryers may be either batch or continuous, with batch dryers recommended for smaller-scale operations and continuous drying for longer and more frequent procedures, where cost effectiveness is vital.

Various sorts of foods may undergo drying out, including fruits, vegetables, meats, and fish. Furthermore, spray drying and freeze drying are utilised to create instant coffee and tea. To get the best outcomes, it is necessary to consider the proper temperature and drying length for each food item.

**3. Principle of modern food preservation technologies**

**3.1 Nanotechnology**

Nanotechnology is the use of microscopic particles in food preparation. Despite being often employed, this strategy is ineffective. It is harmful to both the environment and human health. This kind of nanostructured material may accumulate in the body and result in death. By doing further studies on the physical and biological aspects of these nanoparticles it may be able to surmount these constraints. This guarantees that the food maintains its colour as well as the soluble state of the nutrients remains unaltered throughout the manufacturing process. Using active packaging for food also proves significant as it prevents food from microorganisms (Ahmad *et* *al.*, 2021; Sahoo *et a*l., 2015). To make nanocomposites, such as silicates that protect food from UV, several polymers are used. Nano biosensors are utilised to locate foodborne pathogens or food deterioration material (Ronholm *et al.*, 2016). Foods that have not been significantly or processed are preferred by consumers. Limited food preparation, on the other hand, reduces the shelf life of food by causing increased metabolic activity (respiration), which produces substantial levels of ethylene and exposes food to microbes like the processed mango, which is frequently seen in tropical and subtropical areas. These minimally processed meals are shaped into slices using techniques like chemical dipping and pectin coating that stop the flesh from browning. The ability of food packaging to operate as a barrier against gases has improved with the usage of nano-bio composites for food packaging different nanoparticles' uses in food packaging (García‐Soto *et al.*, 2011)



**Figure 1 Application of nanotechnology in food industry**

**3.2 Hydrolysis of pectin**

Pectin hydrolysis is a method of lowering a pectinase enzyme's activity. During the process of ripening, the pectin in fruit walls of cells begins to generate pectinase, causing food to break down and become softer. Mechanical injury may also trigger the pectinase. Employing pectin methyl esterase avoids rotting. Pectin and alginate are the two most commonly employed coatings on food since they assist extend the storage life and retain the staying fresh of little-treated goods. Additionally, standard approaches like physical, chemical, or biological methods are applied (Silva *et al.,* 2018).

**3.3 Pulsed Electric Field**

PEF is a food processing technique that uses short, high-voltage pulses to inactivate germs. (Morsy *et al.*, 2016). PEF works against vegetative bacteria but not spores. Because it is more expensive, only works with fluids, and is less efficient overall, it is less effective than high-pressure processing (HPP)(Sahoo *et al*., 2015).

**3.4 Pasteurization**

Pasteurisation is a method of food preservation that use heat to eliminate unwanted germs. This increases the duration of storage of food without compromising its nutritional content appreciably. Pasteurisation was invented in the 1860s by Louis Pasteur and is now an accepted technique for preserving milk, juice, and other foods. There are two types of pasteurisations: high-temperature, short-time (HTST) pasteurisation and ultra-high temperature (UHT) pasteurisation. Food is heated to 71.7°C (161°F) for 15 seconds during HTST pasteurisation, and 135°C (275°F) for 2 seconds during UHT pasteurisation (Amit *et al.,* 2017a).

Pasteurisation is a safe and effective method of food preservation; however, it does not eliminate all microorganisms. Pasteurisation can kill some bacteria, such as spores. These bacteria, however, are usually not hazardous and will not multiply in pasteurised food. Other heat-based food preservation technologies, such as PEF and HPP, exist in addition to pasteurisation (Chiozzi *et al*., 2022). PEF inactivates germs using short, high-voltage pulses, whereas HPP kills bacteria with high pressure. These procedures are newer than pasteurisation, but they are gaining popularity since they may preserve food without compromising its flavour or texture ( Sivertsvik *et al.*, 2002).

**3.5 High-Pressure Food Preservation**

A method termed high-pressure preservation of food only affects the non-covalent connections between food particles, conserving nutrients and avoiding food deterioration by modifying the food's structure. This technique works by lowering the volume and raising temperatures (Hyldgaard *et al.*, 2012)

**3.6 Hurdle Technology**

The use of various compounds that inhibit or reduce the metabolic activity of food is referred to as hurdle technology. There are several preservers. The pH, temperatures, water, and different lactic acid microorganisms that hinder food from fermenting could all be barriers (Pundhir & Murtaza, 2015).

**3.7 Antimicrobial agents**

Antimicrobial substances are also used to preserve food because they stop the growth of germs. These can occasionally be acquired by animals, as well as from some plants. The two types of bacteria are both killed by bacteriocins, a type of plant-based antibacterial agent (Hintz *et al.,* 2015). Animals are a source of antibacterial compounds as well since lysozymes are used to preserve eggs and other animal products (Ahmad et al., 2021). Lactoferrin is additionally used as an antibacterial agent. It is formed from mammalian secretions like saliva or tears, which reduce the environment's iron content and stop bacterial development and food spoiling (Ronholm *et al.*, 2016).

The inactivation of microbes in frozen food is a result of irradiation. Pathogenic bacterial strains can be successfully eliminated using gamma radiation and X-ray. Cobalt 60 radiation, which kills microorganisms and is easily penetrating, is used in the gaming sterilisation process to eradicate vibrio from live oysters. For the eradication of microorganisms to be effective, a particular amount of these radiations is required.

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**3.9 Microwave heating technology**

The microwave technology was used to enhance the preservation time of kiwi puree while maintaining the fruit's colour and bioactive components (Ahmad *et al*., 2021).

Microwave heating has a higher penetrating power than other conventional technologies, a higher heating rate than other traditional heating methods, and a higher heating efficiency that reduces processing time. This method is therefore highly effective in preventing bacterial and enzymatic degradation that harms fruit trees while also preserving the colour, bioactive chemicals, and antioxidants (Benlloch-Tinoco *et al*., 2015).

**3.10 Cold plasma technique**

It aids in assuring the longevity of food. The fourth condition of substance, after solids, liquids, and gases, is referred to as plasma. It produces microbial inactivation, prolonging the freshness of new food. Because it is a surface phenomenon, it is ineffective against in vitro organisms such as bacterial and tissue enzymes. This limits microbial development by disrupting cells using electroporation techniques . The plasma device, gas composition, exposure method, and surface of treatment all affect how effectively microbes are inactivated. An increase in air humidity boosted the effectiveness of microbial elimination. Cold plasma exceeds warm plasma in terms of killing microbial spores, keeping food from hazardous pathogens, and storing a range of foods (Thirumdas *et al.,* 2015).

When plasma is administered to microbial cells, malondialdehyde (MDA), which contributes to the formation of DNA adducts and damages cells, is formed. Water is required for the effects of plasma because moist materials are more reactive to plasma. When bacteria and water interact, most reactive and cell-damaging OH+ ions are formed . When atoms of oxygen and the lipid bilayer that exists in the living tissues of microbes interact, the cell's proteins, DNA, and lipids undergo changes (Tola *et al*., 2018). Since plasma changes the three-dimensional structure of most reactive enzymes, which are more active and potentially destroy food products, it can also be used to deactivate enzymes (Sharif *et al.,* 2017). The formation of phenolic substances and antioxidants in food is also aided by plasma, which increases the food's shelf life and preserves it (Sampels, 2015). Additionally, it affects the rates of seed germination. Plasma helps break seed dormancy, which promotes seed germination. When a delay in seed germination is necessary, cold plasma is supplemented with CF4 and octadecafluorodecalin (Thirumdas *et al.,* 2015).

**4. Traditional Food packaging material**

**4.1 Glass**

The first glass food storage containers are thought to have appeared approximately 3000 BC. Glass have been utilised in packaging food for an extended period of time. Glasses had an extremely long history of application in food packaging. Silica, alumina, sodium, and calcium carbonate are heated to extremely high temperatures throughout the glassmaking process until the mixture dissolve into a thick fluid mass that can be made into the moulds McKown 2000). Glass provides several benefits for applications in food packaging (Marsh & Bugusu, 2007). The soft drink and alcoholic beverage industries continue to be the key drivers of glass packaging in India. Glass is no longer being used for pharmaceutical purposes as stiff polymers continue to replace traditional glass packaging.

|  |  |  |
| --- | --- | --- |
| Table 1  Traditional Food packaging material | | |
| Sl.NO | Materials | Applications |
| 1 | Processed skins | * skins from animals like leather, and pig and goats hides were used as containers for fluids like water, beer, oil etc. * They supplied non-breakable and sturdy packing |
| 2 | Earthenware | * Clay pots arose in the Neolithic era and offered robust, anti-microbial packing for liquids and edibles like the curd, beer, honey etc. |
| 3 | Leaves | * Plant leaf like banana, lotus, etc. were often used to wrap dishes. |
| 4 | Glass | * Inert glass jars and bottles offered total barrier to gases and microorganisms. |
| 5 | Paper | * Paper bags, cartons, wraps etc. were used for dry items, meats, biscuits etc. Paperboard supplied stiffness for shipping boxes |
| 6 | Cotton, jute | * Fabrics like cotton and jute were used for bags to convey grains, flour etc. |
| 7 | wood | * Wooden crates and boxes were utilised for bulk shipment of goods, vegetables, fish etc. |

**4.2 Metal**

The most adaptable packing material is metal. It combines excellent flexibility and aesthetic potential, great physical safeguarding and barrier qualities, recyclable possibility, and consumer acceptance. Steel and aluminium are the two types of metals that tend to be utilised in packaging. Aluminium is a heavyweight, silvery-white metal that is widely used to make metal cans, aluminium foil, and laminated paper or plastic packaging.

Polymerization, referred to as polymerization by condensation , is a method used to manufacture polymers. In polycondensation, smaller-molecule products like methanol and water are created as the polymer chain grows as a consequence of condensation reactions among molecules. PET is a form of polyester which is primarily usually used to package goods, notably drinks and mineral water. PETE is widely utilised to produce bottles made from plastic for carbonated drinks (Marsh & Bugusu, 2007).

**4.3 Paper**

The majority of the cellulosic fibre, generally referred as wood pulp, needed to generate paper originates from trees. In addition to wood pulp, materials including flax, cotton, esparto, fibre, hemp, manilla, and jute may also be used to manufacture paper. Some cellulose qualities are impacted by when the wood's filaments are removed. The fibres are pulped, coloured, and then processed with compounds like strength agents and slimicides to create the final paper product. Products that commonly employ paper and paper boards includes cardboard boxes, dairy cartons, folded boxes, bundles and bags, containers, packaging material, tissue paper, and plates made of paper .

Coated or uncoated sheets composed of kraft and sulfite pulp constitute papers laminates. They may be laminated with aluminium, plastic, or other materials with comparable functional capabilities to improve certain features. To make the paper heat-sealable, polyethylene might be used to laminate the paper. But the cost of paper is greatly increased by lamination. Laminated paper is used for packaging dried commodities like ready-to-serve soups, spices, and ground herbs (Marsh & Bugusu, 2007).

**5. Principle Modern Packaging Technologies**

**5.1 Active Packaging Systems**

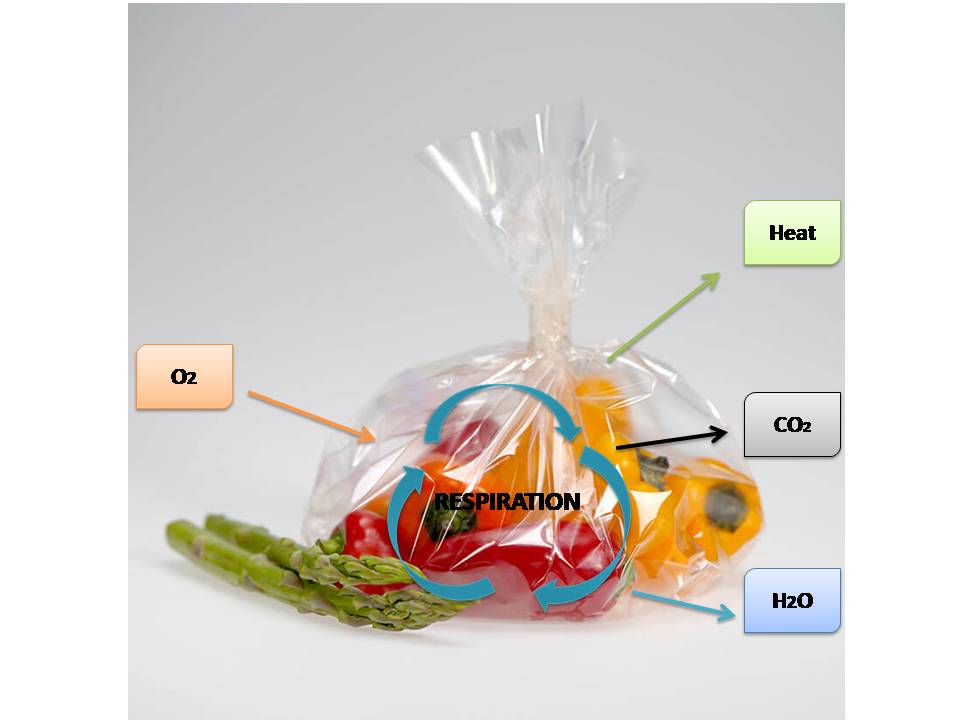
Active materials were produced expressly for use with food or its surrounds, altering their composition or qualities to keep the organoleptic or sensual aspects of the good intact while preserving its nutritional content for a longer length of time (Azeredo & Correa, 2021).

Active compounds commonly employed in packaging for food include antimicrobial agents, anti-oxidants, flavour, light blockers and gas scavengers.

**5.1.1 Modified Atmosphere Packaging (MAP)**

The increased need for fresh, nutritious, and long-lasting meals demands packaging design innovations. In this context, new, intelligent, and smart packaging that is capable of detecting and conveying information from packaged meals has been produced(Azeredo & Correa, 2021).

MAP of foods relies on changing the atmosphere within the package, which is accomplished through the natural interaction of two processes: gas transport through the packaging and product respiration. Newly harvested Vegetables and fruit are more sensitive to harmful organisms after harvesting due to higher respiration rates (Yousefi *et al*., 2019). The respiration rate of fresh agricultural commodities can be lowered by using various preservation strategies. Modified atmosphere packaging (MAP) is a method that alters the amount of gases in the package around the produce to improve shelf life and food quality preservation. Modified environment packaging modifies the atmosphere within the box by using three basic gases: carbon dioxide, nitrogen and oxygen. The modified environment comprises more CO2 and less O2. The concentration of gases varies according to the type of fresh product packaged. When compared to traditional storage systems, MAP extends the shelf-life of products from days to weeks. MAP protects against physiological damage, disorder, reduction in weight, and fungus development.



**Figure 2 Modified atmospheric packaging**

**5.1.2 Vacuum packaging**

Vacuum packaging involves sucking the air out of the product package and sealing it tightly it. This extends storage by preventing microbial growth and enhances hygiene by minimising the risk of cross-contamination between items. Vacuum packing additionally protects against dryness and weight loss while preserving flavour.

The efficiency of vacuum packaging is heavily dependent on the packing material utilised. The vacuum packaging material must possess an effective barrier property to prevent the entry of moisture and oxygen for a specified amount of time. The amount of oxygen that enters the package is determined by the thickness of the package (Kumar & Ganguly *et al.,* 2014). Vacuum packaging is oil and chemical resistant, as well as transparent. Vacuum packaging ensures product safety while lowering economic loss in the storage of fish and fisheries products (Ochieng *et al.,* 2015). Vacuum packaging combined with icing significantly increases product shelf life (Rajesh *et al.,* 2002).

**Vacuum Packaging applications**

* A straightforward method for packaging commodities that require oxygen protection.
* Controlling the humidity content of the vegetables
* The development of aerobic spoilage bacteria is inhibited.
* Lower prices than rigid containers
* Goods have a longer shelf life.

**5.1.3 Controlled release packaging**

Controlled release packaging (CRP) is a novel sophisticated approach that controls the release of active chemicals that is contained in packaging and has potential uses in food packaging through the controlled dispersion of the active component.

In CRP, the kinetics and controlled release method are crucial elements. These CRP can govern the regulated release of active substances and control when they are released and the duration it needs to release. If active chemicals are released fast indicates there will be excess active substances that might be also lost via contact with food. For an instance, if it is delivered slowly indicates it will be not adequate to halt food spoiling (X. Chen et al., 2019).

Active packaging solutions for food may be applied in a number of ways. Included in them are: • Active sachets inside food packaging

• An active substance may be injected direct into the polymeric matrix, coated onto the polymers, or immobilised on the polymeric surface.

• The specific active substance and the planned release profile decide the choice of technique to utilise.

**5.2 Intelligent Packaging Systems**

Intelligent food packaging technologies are devices that keep track of both the packaged food and the environment in which it is stored. They may produce real-time information about food quality and safety, which can aid in the prevention of food-borne illnesses (Yousefi *et al*., 2019). Intelligent packaging solutions do not immediately improve food shelf life in the same way that active packaging does. Instead, they share knowledge on the safety of food with stakeholders in the food supply chain.

In intelligent packaging systems, three core technologies are used: indications, sensors, and data carriers. Data carriers are devices which hold and send data about food or its surroundings (Azeredo & Correa, 2021; Ghaani et al., 2016).

**5.2.1 Indicators**

Indicators are tools that can be used to keep track of the food's quality. They can be used to convey information about the food's real exposure to environmental factors or its current quality state. Although fluorescent dyes and other forms of indicators are also utilised, colourimetric dyes make up the majority of indicators (KB *et al.,* 2015).

Food quality may be adequately and instantly checked with the use of clever packaging. It may be used to assess food freshness, circumstances of storage, expiry dates, safety examinations, and microbiological development. Active indicators, which are dye-based molecules that allow the assessment of food's chemical characteristics, are employed to achieve this. Real-time monitoring is possible for temperature fluctuations during preservation, amounts of oxygen, and microbiological activity (Azeredo & Correa, 2021).

considering its link with food products, intelligent package signs can reveal details regarding the presence or lack, quantity, or strength of an adverse effect of a targeted compound (Azeredo & Correa, 2021). Temperatures and freshness signs are the two most popular kinds of food packing indicators (Ghaani *et al.,* 2016).

**5.2.1.1 Temperature Indicators**

Temperature regulation is critical for food stability, particularly for frozen and refrigerated foods. Temperature control is crucial to preserve the food's freshness and prevent food spoilage.

Temperature indicators are secondary indicators of food freshness and quality. since they rely on temperature variations. They provide information on the food's exterior environment, such as if it was exposed to extreme heat or cold (KB *et al.*, 2015). Temperature indicators are classified into two types: thermochromic and time-temperature indicators (TTIs). Thermochromic indicators alter colour in reaction to temperature changes, whereas TTIs monitor the amount of time a product that have been kept to a specific temperature (Khan *et al.*, 2022).Temperature abuse information can be used to alert consumers to possible food safety hazards, such as the growth of microbes, the denaturation of proteins, or the breakdown of emulsions.

**5.2.1.2 Freshness indicators**

The role of the freshness indicator is to identify the chemical and microbiological variations that trigger the spoilage of food. In meat products, freshness indicators can be based on naturally occurring amines and hydrogen sulfide (H2S), which are produced during meat spoilage (Yousefi *et al.*, 2019).

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| --- | --- | --- |
| Table 2  Freshness indicator application | |  |
| **Analyzed property** | **Identification** | **Reference** |
| Meat | Food spoilage by the release of amines and hydrogen sulphide | (Y. Zhang *et al.*, 2019) |
| Seafood | To identify microbial spoiling by release of volatile substance | (Morsy *et a*l., 2016) |
| Fruits | Identifies ripeness based on release of ethylene | (Kalpana *et al.*, 2019) |
| Apple ripeness | Identifies release of aldehydes | (Kim et al., 2018) |

Amines are organic compounds that are produced by the breakdown of proteins. They can have a fishy or ammonia-like Odor, and they are often associated with spoilage. H2S is a gas that is produced by the breakdown of sulphur-containing amino acids. It has a strong sulphurous Odor, and it is also associated with spoilage. Freshness indicators that are based on amines or H2S can be used to check the freshness of meat goods. These indicators can change colour or release a signal when the amines or H2S levels reach a certain threshold. This can help consumers to determine whether a meat product is still fresh and safe to eat (Zhang *et al*., 2019).

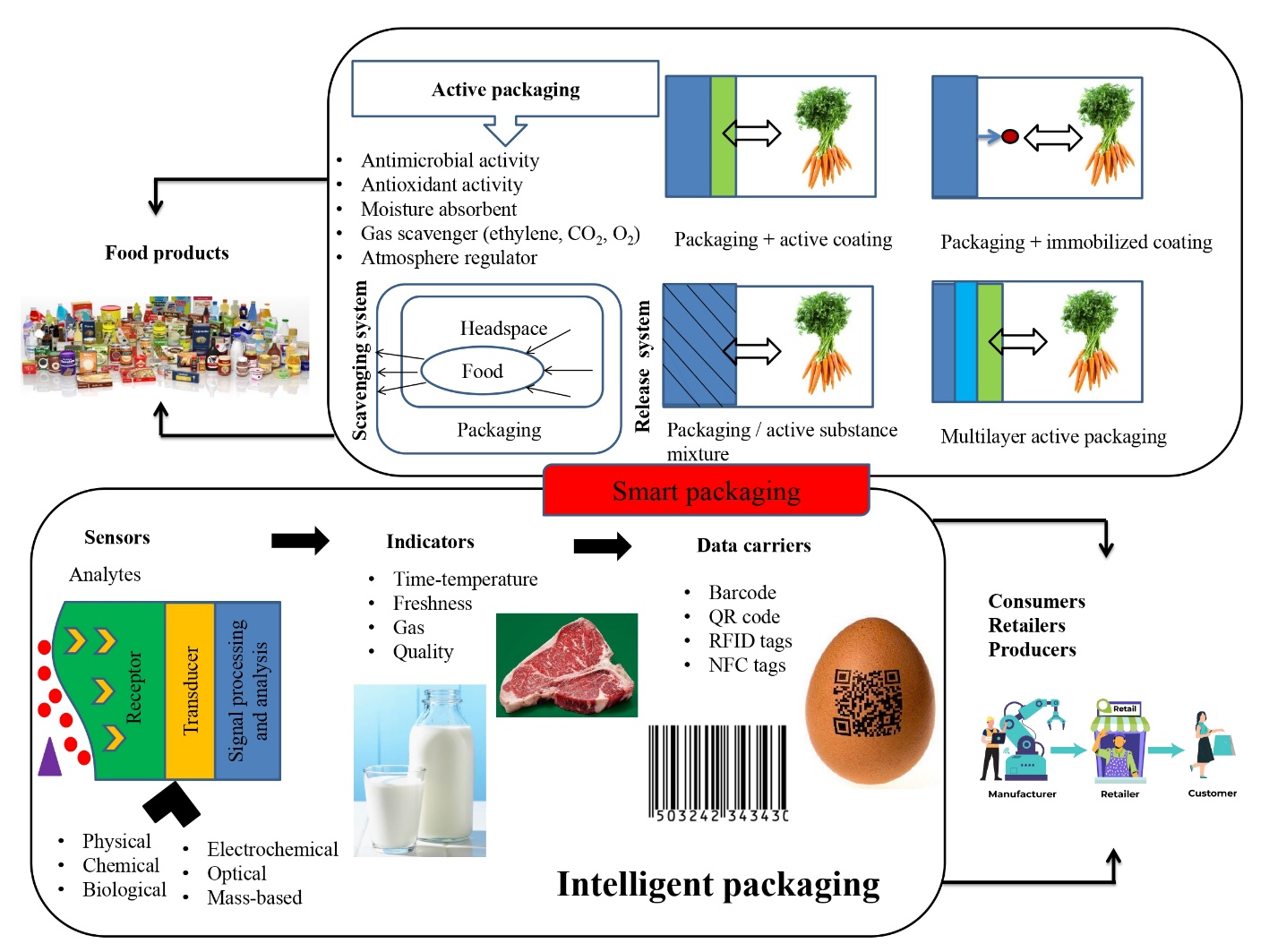
**5.2.2 RFID**

Radiofrequency identification (RFID) tags are employed to monitor food goods as they travel through the food supply chain. They are not commonly used to acquire data regarding the nutritional value of food, but they may be utilised to automate procedures, assure tracking, prevent theft, and defend against counterfeiting (Ghaani *et al.,* 2016). An RFID system consists of three components: an RFID antenna, a chip, and a reader. The antenna communicates with the chip, which stores information about the product. The reader emits waves that are reflected by the tag, and the information from the tag is then read by the reader. The reader then sends the information to a host computer for storage and processing. RFID technology is a valuable tool for the food industry, as it can help to improve efficiency, traceability, and security. However, it is important to note that RFID tags are not typically used to gather data about the quality of food (Bibi *et al.,* 2017). RFID labels with CO2 and O2 sensors were developed to regulate vegetable ripeness while also improving the safety and quality of dairy products (Wu et al., 2020).

**5.2.3 Barcode**

A barcode is a machine-readable sequence of parallel bars and spaces. The pattern reflects hidden encoded data, which the machine decodes and sends to a system where it is kept and processed. Barcodes help identify products, maintain inventory, and automate checkout processes. These are common in retail stores, warehouses, and other places where products are handled and tracked (Chowdhury & Morey, 2019).

Barcodes are classified into two types: linear barcodes and 2-dimensional barcodes. The most frequent type of barcode is a linear barcode. They consist of a series of parallel bars and spaces that can be read by a scanner. Barcodes are a valuable tool for businesses that need to track products and inventory. They can help to improve efficiency and accuracy, and they can also save businesses time and money (Ghaani et al., 2016; Sohail et al., 2018).



**Figure 3.Smart packaging**

**5.2.4 Smart sensors**

The function of chemical sensors is to identify the chemicals quickly using chemical sensors by converting chemical data into measurable output signals with the help of software.(Ghaani *et al.*, 2016) The chemical sensors also identify the gases that are released by spoiled food. when meat is spoiled means it releases NH3, ethanol and H2S gases that can be detected by sensors. (Senapati & Sahu, 2020).

In smart packaging, hybrid sensors are developed to function as wireless sensors that are capable of tracking amines that are released by beef, fish and meat items (Andre *et al.*, 2021).

The harmful compounds will be transferred to the foods from packaging material during their interaction, so it is necessary to detect that using electrochemical sensors (Ghaani *et al.,* 2018). Biosensors are helps in identifying the quality of food and also it can detect harmful organism that causes food-borne diseases (Ghaani *et al.,* 2016). The coatings that are present in intelligent packaging will react when it encounters bacterial antigens like aflatoxins (Costa *et al.,* 2017). In recent advances, nanomaterials are identified as active compounds in sensors as it contains unique optical, high surface area and electrical characteristics that help in the detection of signals from sensors (Ghazanfari *et al.*, 2021). Nanomaterials can detect various targets like microorganisms, poisons, irritants and antimicrobial agents using their enhanced detection and transduction mechanisms

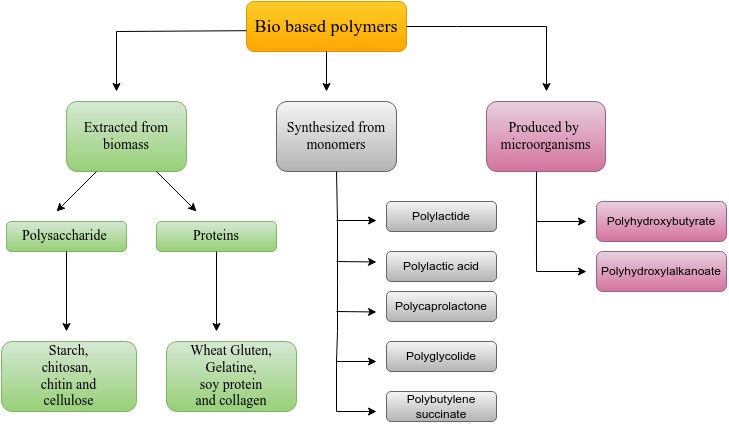
**5.3 Sustainable Packaging Materials**

Utilising recyclable materials to create packaging film is known as sustainable packaging, and it also uses life cycle evaluations and analyses to reduce the packaging's ecological footprint and environmental impact**.**

**5.3.1 Bio-Based and Biodegradable Food Packaging Materials**

Plastic materials for packaging have limitations because of their harmful impact on the ecosystem. Carbon dioxide is released when petroleum-based materials are produced. According to their place of origin and way of production, bio-based polymers or bio-polymer-based packaging materials can be divided into three primary categories.

* Directly derived polymers from biomass
* Monomers synthesised from renewable resources to produce the polymers
* Directly derived polymer from microbes

** Figure 4 Bio based Food packaging materials**

* **Directly derived polymers from biomass**

These polymers come from marine and agricultural resources, and they possess a high degree of intramolecular connection and crystallinity.

* **Directly derived polymer from microbes**

These microorganism-produced polymers are members of the polyhydroxy alkanoate family . They are linear polyesters that are recyclable and biocompatible and were made from renewable resources like sugar.

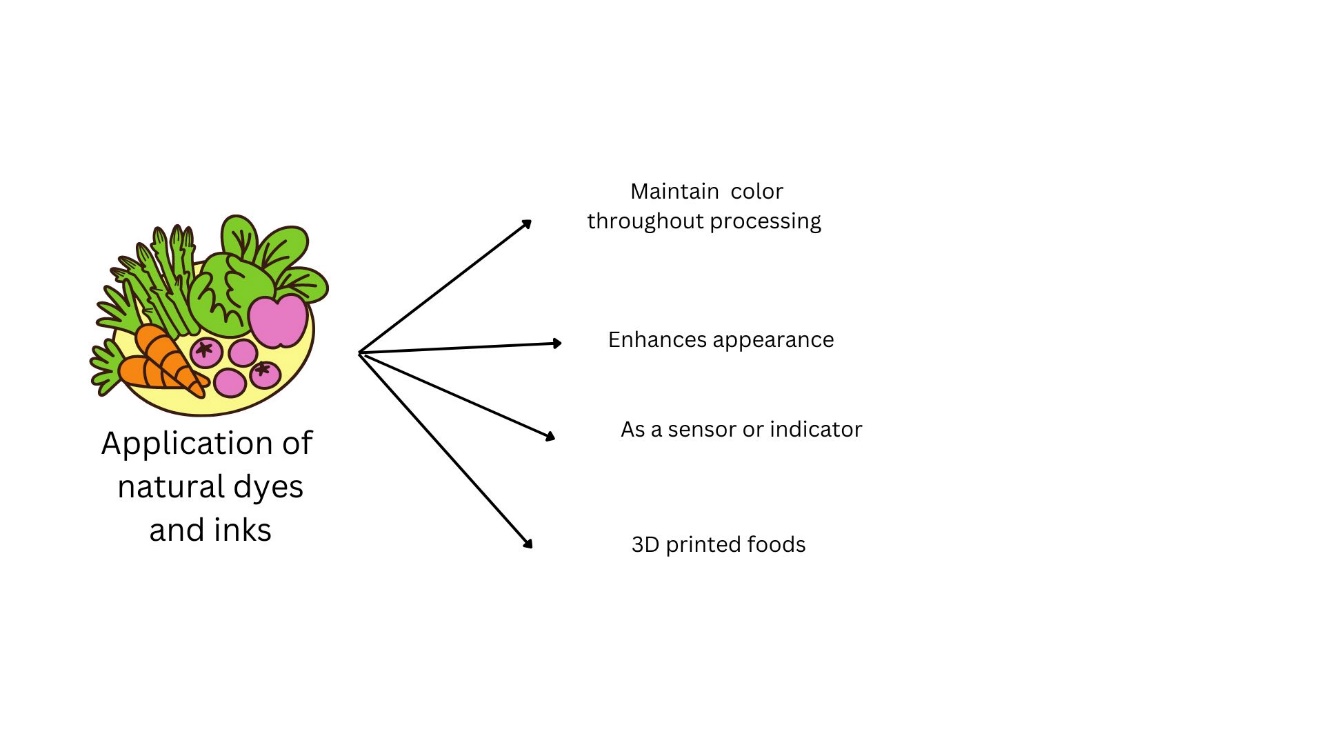
Industrial agri-food waste is usually thrown into the trash, but It can have applications like the creation of polymers and organic compounds. There is a special interest in the utilisation of chitosan and its derivatives because they possess an antibacterial effect (Castillo *et al*., 2017).

**5.3.2 Food Packaging Bioadhesives**

An adhesive is a substance that can bind to multiple specimens. Nowadays synthetic adhesives are used previously natural adhesives were utilized. Biobased adhesives are formulated using biopolymers that are derived from natural things like plant-based gums and animals(Ocaña López, 2017). To make biobased adhesive eco-friendly biopolymers are the best choice that includes lignin, tannins, proteins and carbohydrates. These adhesives are quick to become adherent yet are weak. It is accessible to be blended with water in fluid and powder form and also sold as dispersions (Dohr & Hirn, 2022) .

**5.3.3 Biobased pigments & Dyes**

Food safety and quality awareness are increasing globally. There is an availability of natural dyes or colourants which can be used in the food industry. And research for using natural colourants is ongoing and already performed since they have calming colour, are non-hazardous like synthetic dye, it is non-carcinogenic and has various applications. The colourimetric sensors are utilized to indicate colour changes with dissimilarities in pH, temperature and gas in food products (Saxena & Raja, 2014).

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**Figure 5 Application of natural dyes and inks in food industries**

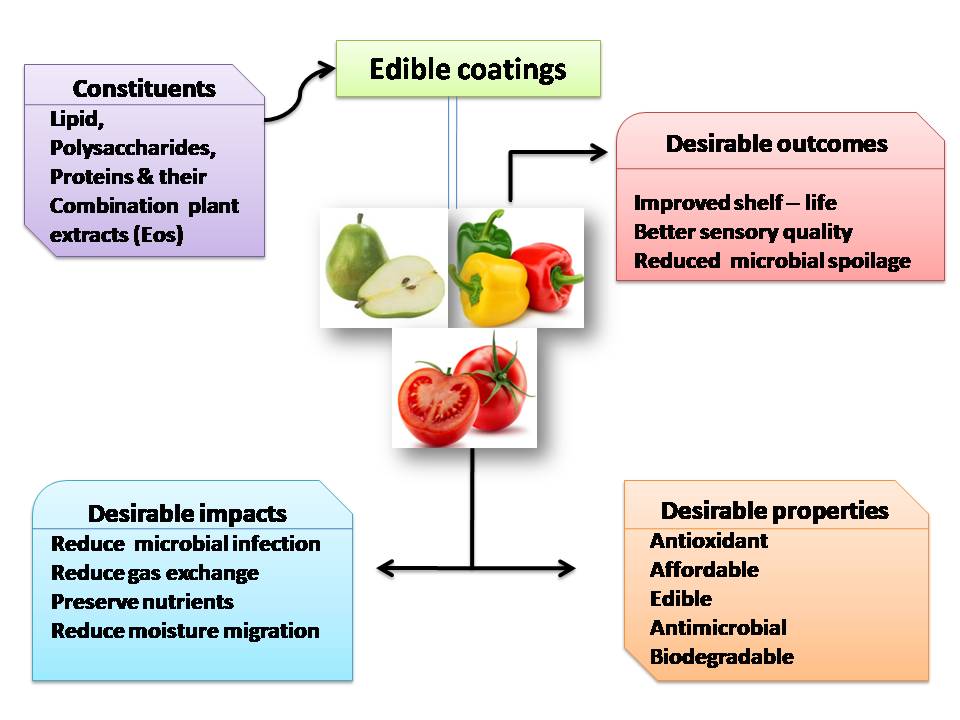
To produce 3D-printed food, bio inks must be included as a package item that is placed into the printer. A period of three weeks of room temperature storage of dried 4D samples revealed colour and anthocyanin stability. Similarly, (C. Chen *et al.*, 2021) explained how microwaves were used to speed up the colour transition of printed in 3D curcumin lotus root gel. The 4D printed material can be used as an indicator for food packaging. The natural dye act as an antibacterial agent and antioxidant for using it as a 3D printer (Phan *et al*., 2021).

**5.3.4. Edible packaging**

Edible packing materials are quite comparable to manufactured and non-edible materials. Also have to be specific as barriers material to control and limit moisture, oils, fats,  gases, volatile taste compounds, and odours migration from food, and they must increase or at the very least preserve the mechanical integrity of packed food. The most important attribute, however, is how resistant they are to water vapour migration, which helps to keep food fresh. The major advantage lies in the fact these materials are biodegradable.

Edible packaging materials include coatings, edible films pouches, and sheets. Although the initial three are separate structures that can be applied to food or sealed into bags and as a thin layer edible coating are coated on surface food (Espitia *et al.,* 2014).

The edible packing material component should be chosen based on the type (for example, fruits, dairy, vegetables and coffee) and circumstances for storage, such as temperature and relative humidity (Parente *et al.*, 2023).



**Figure 6 Edible coating**

The following categories apply to edible packaging materials:

1. Materials acquired directly from organic sources, such as those obtained from aquatic, agricultural, and animal sources
2. Materials obtained from genetically modified microbes, such as polysaccharides and certain active chemicals.
3. Materials produced chemically, such as surfactants, plasticizers, and other active substances.

Additionally, the protein-based edible covering has outstanding mechanical and barrier qualities against oil, oxygen, and smell. However, the resistance to water-based vapours is limited. In the production of edible films, collagen received the greatest attention. Polysaccharide-based films may aid to delay ripening and extend the shelf life of coated food (Raajeswari & Pragatheeswari, 2019). Shellac is used as an edible covering for desserts and fresh products. Composite materials are composed of edible ingredients that have been mixed to eliminate defects .Active biodegradable films comprised of corn starch and chitosan have been developed with a blend of citrus essential oil and grape extracts from seeds . The majority of composite films are composed of hydrocolloid, protein and lipid components that are held together by a polysaccharide or lipid material distributed in the form of a protein matrix or polysaccharide.

**6. Applications of Modern Packaging Technologies**

**6.1 Vegetables and fruits**

In 2021, India showed the potential to become an exporter with $750.7 million worth of fruits and vegetables. However, the perishable nature of these products requires careful internal packaging to maintain quality and ensures a long shelf life (Lee *et al.*, 2019).  Fruits and vegetables need gas exchange facilities to maintain quality. Active packaging's main goal is to maintain oxygen, moisture and ethylene levels and to inhibit microbial development. Some products, such as bananas and mangoes, can be physically damaged by high temperatures. Factors such as humidity, temperature and oil composition play an important role in preventing the effects of harmful bacteria. Proper handling and handling, especially during transportation, is important to prevent microbial contamination (Pant & Thielmann, 2018).

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| Table 3  Modern food packaging application for fruits and vegetables | | | | |
| Sl.NO | Fruits and vegetable | Packaging type | Application | Reference |
| 1 | Lettuce | Ethylene scavenger  (Zeolite) | Decreases colour change, delays loss of weight, and resists pH change in lettuce and iceberg lettuce after twenty-one days of storage. | (Gaikwad *et al.*, 2020) |
| 2 | Tomato | Triticale films with KMnO4 | After 21 days of storage slows the ripening of cherry tomatoes. | (Aragüez *et al.,* 2020) |
| 3 | Grapes | Edible films | improves the fresh green grapes' postharvest shelf life for a period of 21 days | (S. Kumar *et al.,* 2019) |
| 4 | Avocado | RFID Tag | Monitors ripening | (Occhiuzzi *et al*., 2020) |
| 5 | Guava | Moisture scavenger | Unaffected by freezing damage or bacteria. | (Murmu & Mishra, 2018) |

Temperature time indicator can be utilized as a marker to check the chemical alterations and microbial viability in vegetables and fruits. The ethylene absorber prevents weight loss, delay ripening, and maintains firmness during storage (Jiang *et al*., 2020). Since ethylene, a phytohormone that causes fruit ripening can affect product quality during storage and export, gas change is required in fruit and vegetable packaging. The potassium permanganate, silica, and alumina are the ethylene absorbers that are placed in packages to extend the preservation time of vegetables and fruits such as apples, kiwis, apricots, bananas, mangoes, tomatoes and avocados (Murmu & Mishra, 2018).

**6.2 Bakery and Confectionery Products**

Bread has a low shelf life of four to ten days, cakes last for weeks and cookies for a few months. Refrigerating baked items leads to a loss of taste and texture. The baked items are prevalent to mould and fungus. The baking process usually destroys a large number of viable fungal spores, other spores may nevertheless survive processing such as packaging and refrigeration (Qian et al., 2021). Baked foods are influenced by oxidation, fluid loss and gain. The primary cause for bakery food spoilage is oxygen-permeable packaging or defective sealing or bakery foods capacity to retain air (Noorlaila *et al.,* 2017).

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| Table 4  Modern food Packaging application for bakery and Confectionery Products | | | | |
| Sl.NO | Food item | Packaging type | Application | Reference |
| 1 | Pizza crust | Allyl isothiocyanate sachets incorporation | Up to 30 days of storage, it suppresses the spread of A. parasiticus and the generation of Aflatoxins.  . | (Qian *et al*., 2021) |
| 2 | Sponge Cake | Nanocomposite emulsion film | Suppresses fungus development and keeps the cake's chemical and organoleptic properties. | (Sahraee *et al.,* 2020) |
| 3 | Pizza crust | allyl isothiocyanate sachets | Inhibits the generation of Aflatoxin | (Qian et al., 2021) |
| 4 | Bun | Active packaging | Increased shelf life | (Kuswandi, 2020) |

Oxygen sensors are capable of checking the oxygen level in baked items. The baked items with vacuum or modified atmospheric packaging will be attached with oxygen sensors and oxygen levels will be checked regularly to check the quality of food (Hempel et al., 2013)The removal of oxygen from the package and the addition of antimicrobial agent results in extending the preservation time of baked items .The baked products can be preserved with quality with the help of both active and intelligent packaging.

**6.3 Dairy and dairy products**

A healthy diet plays an important role in health and well-being, dairy contains nutrients as well as tasty . Because of nutrient richness and higher water content, it possesses lower shelf life. Because of nutrient richness and higher water content, it possesses lower shelf life. The dairy food composition and its nutritional richness favour bacterial proliferation (Hamad, 2012). Food spoiling occurs due to the exponential expansion of harmful organisms (Karaman et al., 2015).

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| Table 5  Modern food Packaging application for dairy and dairy products | | | | |
| Sl.NO | Food item | Packaging type | Application | Reference |
| 1 | Cheese | Smart oxygen sensors | cheese quality level of deterioration was extended | (Deshwal *et al*., 2021) |
| 2 | Butter | Chitosan-TiO2 and chitosan-Ag/TiO2 active papers | extended shelf life of clarified butter of up to six months | (Apjok *et al.*, 2019) |
| 3 | Yogurt | Natamycin-grafted films | increases yogurt's shelf life to 23 days. | (Anari *et al.,* 2022) |
| 4 | Paneer | Edible film made of essential oils | Increased shelf life | (Karunamay *et al*., 2020) |

Smart packaging technology is the best technique to increase shelf life and to decrease contamination of dairy products by utilizing antibacterial, antioxidant and oxygen scavengers packaging material. The preservation time for dairy products may be significantly shortened by excessive oxygen levels in the packaging, which can promote microbial development and cause disagreeable odours and off-Odors, colour changes, and nutritional distortions (Soares et al., 2009). For limiting the growth of fungi and microbes’ oxygen scavenging can be utilized (Karunamay *et al*., 2020).

Packing film function as an expiration date indicator, packing films contain pectin, fragrant oils, and beta-carotene. As a result of oxidation, the amount of -carotene is greatly reduced, and the colour of the packaging film changes  (Asdagh & Pirsa, 2020). The carbon dioxide gas contains antibacterial properties that increase the preservation time and quality of milk (Mirza et al., 2020). Milk powder is usually packaged with inert gas N2 to avoid disagreeable taste and it can last up to 12 months (Anari et al., 2022).

Consumers can make educated decisions about their purchases by utilizing the benefits of smart packaging and making a profit from it.

**6.4 Fresh produce and Meat products**

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| Table 6  Modern food Packaging application for fresh produce and meat products | | | | |
| Sl.NO | Food item | Packaging type | Application | Reference |
| 1 | Chicken | Whey protein packaging films with seaweed extract | oxidation of lipids had been delayed for up to 21 days | (Andrade *et al.,* 2021) |
| 2 | Fish | Alizarin-added films with chitosan | Exhibited antimicrobial and delayed lipid oxidation | (Ezati & Rhim, 2020) |
| 3 | Eggs | Time-temperature indicator identifies pathogenic bacterial growth | Increases yoghurt's shelf life to 23 days. | (Chowdhury & Morey, 2019) |
| 4 | Shrimp | Edible film with nano Fiber | Increased shelf life of shrimp up to 12 days | (Nazari *et al.*, 2019) |
| 5 | Pork | pH-sensitive packaging films | Pork freshness was monitored | (Qin *et al.*, 2019) |

Meat is a nutritious food, but it can also spoil easily. When exposed to air, deoxymyoglobin in meat is oxidized to form oxymyoglobin, which gives meat its characteristic red colour. Over time, oxymyoglobin can further oxidize to form metmyoglobin, which causes meat to turn brown and lose its freshness (Thirupathi Vasuki *et al.*, 2023).

Smart packaging can prevent the spoilage of meat by preventing oxidation using oxygen scavengers, which remove oxygen from the packaging or else carbon dioxide is displaced by oxygen.Consumer awareness and acceptability of smart packaging is growing day by day. Smart packaging is an important tool to reduce food poisoning and to provide fresh and quality products for consumers (Wu et al., 2020)

1. **Comparison of Traditional and Modern packaging and packaging Techniques**

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| Table 7  Comparison of Traditional and Modern packaging and packaging Techniques | | |
| Parameter | Traditional Techniques | Modern Techniques |
| Effectiveness | Due to limited control over preservation factors, effectiveness is moderate. | Very effective due to precise control and combination of multiple hurdles |
| Shelf-life extension | Weeks to months, with some exceptions like canning | Can preserve up to years |
| Nutrient retention | some procedures, including smoking and canning, deplete vitamins and minerals. | Excellent - mild processing preserves nutrients |
| Waste generated | Moderate reuse opportunities for glass, some plastics | Low-weight, thinner materials with a focus on recyclability |
| Cost | Low to moderate | Moderate to high |
| Energy usage | High for canning and freezing, low for salting and drying | Lower with automation and milder processing |

**8. Conclusion**

In conclusion, both the techniques for modern and traditional food storage and packaging have benefits and drawbacks. Modern techniques like modified atmosphere packaging, vacuum sealing, sensors, and improved preservation techniques provide extended shelf life and increased food safety. On the other hand, traditional preservation is based on centuries-old practises that are effective in storing food at a low cost. Modern packaging technologies are now more acceptable because of their application in maintaining the quality of vegetables, dairy, fruits and meat products. Modern packaging technologies are now more acceptable because of their application in maintaining the quality of vegetables, dairy, fruits and meat products. For secure consumption of preserved foods and the prevention of foodborne diseases, proper hygiene, adherence to approved procedures, and monitoring of conditions of storage are essential. This chapter attempts to benefit readers in recognising the fundamentals, applications, benefits, and drawbacks of both traditional and modern food packaging and preservation techniques.

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