

MODERN AND TRADITIONAL FOOD PRESERVATION AND PACKAGING TECHNOLOGIES: PRINCIPLES, APPLICATIONS, AND IMPLICATIONS

Abstract

Food contamination can occur from harvesting from farms to food plates. More than 200 illnesses can occur because of eating contaminated food. Techniques to improve food preservation and packaging are required for a number of reasons, including the fact that they help increase the longevity of sensitive foods, 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 drawbacks, as well as their influence on food preservation, sustainability, and customer preferences. To provide industry experts, researchers, and policymakers with crucial information, this chapter compares and contrasts current and traditional food storage and packaging methods.

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

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I. 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.

II. FOOD STORAGE AND PACKAGING

Food storage and packaging solutions are important for a number of reasons. They help prolong the preservation period of perishable foods, reduce the chances for deterioration, and reduce 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)

Food storage and packaging technology have evolved from centuries-old ways. 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 goals of this chapter were to study the ideas underpinning current food storage and packaging systems and compare them to past approaches. 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 protecting the hygiene, value, and long-term viability of the food supply chain.

III. PRINCIPLE OF TRADITIONAL FOOD PRESERVATION TECHNOLOGIES

- 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). For millennia, root cellars and cold storage have been used to extend the storage longevity of perishable goods like veggies and fruits.

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 storage techniques prolong the freshness of fruit, veggies, and other perishable commodities.

- 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). The most often used smoking methods in the preparation of smoked meat-based foods are traditional 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 oxidation 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).

- 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). Developing nations export a wide variety of canned foods to wealthier nations; in fact, more than 25% of the canned fruits and vegetables that European nations purchase come from developing nations. This trade generates a substantial quantity of foreign cash for low-income countries, particularly canned fish, vegetables, and fruits (Ahmad et al., 2021).

Canning uses techniques that reduces temperature like cooling and heating to stop the enzymes and development of germs in the food (Ahmad et al., 2021; Joardder & Masud, 2019). It is essential to properly prepare raw materials, particularly fish, which may contain dangerous germs including *Clostridium botulinum*, which may be lethal, with the goal to assure safety. 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.

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). Numerous microorganisms, including yeast, bacteria, and moulds, are essential for the fermentation of a wide variety of foods, including meat products, dairy products, and meals made of cereal (Amit et al., 2017). Foods that have undergone fermentation have improved nutritional value, health advantages, and digestion, providing a better alternative to the consumption of dangerous preservatives that contain chemicals (Kårlund et al., 2020, Amit et al., 2017).
5. **Drying and Dehydration:** Dehydration is the process of removing moisture from either liquid or solid food by evaporation. Drying is done to produce a solid product having barely any 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. The drying process may also cause harm to crucial nutrients including vitamin C, protein, thiamine, and fat (Amit et al., 2017). Dryers can be either batch as well continual depending on the specific needs, with batch dryers preferred for smaller-scale operations and continuous drying for longer, more frequent processes where cost efficiency is crucial.

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.

IV. PRINCIPLE OF MODERN FOOD PRESERVATION TECHNOLOGIES

1. **Nanotechnology:** Nanotechnology is the use of microscopic particles in food preparation. Despite being often employed, this strategy is ineffective. 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 al., 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, and shortens food's shelf life 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)

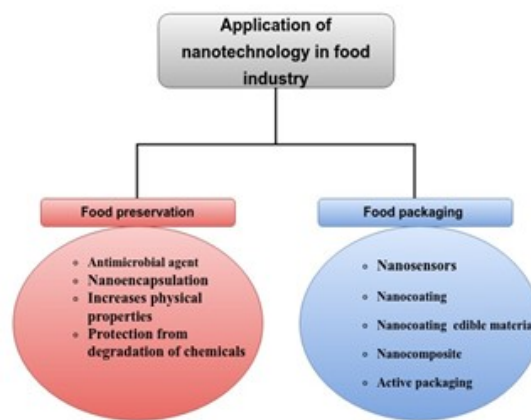


Figure 1: Application of Nanotechnology in Food Industry

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. The two most often used food coatings were pectin and alginate because they help keep little-treated items fresh longer in storage. Additionally, standard approaches like physical, chemical, or biological methods are applied (Silva et al., 2018).
3. **Pulsed Electric Field:** PEF is a food processing method that incapacitates microorganisms using quick, high-voltage pulses (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).
4. **Pasteurization:** Pasteurisation method uses 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 an effective and trustworthy means to preserve food, it does not thoroughly get rid of bacteria. 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 pasteurization (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).

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)
6. **Hurdle Technology:** The term "hurdle technology" refers to the use of different chemicals that impede or lessen the metabolic process of food. 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).
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). Antibacterial chemicals are also found in animals since lysozymes are utilised to preserve eggs and other animal products (Ahmad et al., 2021). Lactoferrin is additionally used as an antibacterial agent. It gets generated by secretions such as tears and saliva, which lower the iron concentration in the environment and prevent bacterial growth and food spoilage. (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. The eradication of microorganisms to be effective, a particular amount of these radiations is required.

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9. **Microwave Heating Technology:** A microwave was used to preserve, maintain and enhance the longevity of kiwi puree (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).

- 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. But it has drawback like surface phenomenon, it is ineffective against 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). Most reactive enzymes undergo three-dimensional structural changes in plasma, making them more active and perhaps destroying food components. Plasma may also be utilised 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 CF_4 and octadecafluorodecalin (Thirumdas et al., 2015).

V. MATERIAL USED IN TRADITIONAL FOOD PACKAGING

- 1. 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).
- 2. 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Plant leaf like banana, lotus, etc. were often used to wrap dishes.
4	Glass	<ul style="list-style-type: none"> • Inert glass jars and bottles offered total barrier to gases and microorganisms.
5	Paper	<ul style="list-style-type: none"> • Paper bags, cartons, wraps etc. were used for dry items, meats, biscuits etc. Paperboard supplied stiffness for shipping boxes
6	Cotton, jute	<ul style="list-style-type: none"> • Fabrics like cotton and jute were used for bags to convey grains, flour etc.
7	wood	<ul style="list-style-type: none"> • Wooden crates and boxes were utilised for bulk shipment of goods, vegetables, fish etc.

- 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).

VI. PRINCIPLE OF MODERN PACKAGING TECHNOLOGIES

- 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.
- 2. MAP (Modified Atmosphere Packaging):** The increased need for fresh, nutritious, and long-lasting meals demands packaging plan innovations. This is 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 rate s(Yousefi et al., 2019). The respiration rate of fresh agricultural commodities can be lowered by using various preservation strategies. To extend the shelf life and preserve food quality, the MAP technique modifies the quantity of gases present in the packaging surrounding the product. 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, with MAP, items possess an expiration date that is weeks rather than days. MAP protects against physiological damage, disorder, reduction in weight, and fungus development.



Figure 2: Modified Atmospheric Packaging

- 3. Vacuum Packaging:** It involves sealing the packaging of the goods firmly after sucking out the air. 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 packing material used has a big impact on the way vacuum packaging works. The vacuum packing material must have a strong barrier characteristic to keep out oxygen and moisture for a certain period 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 fisheries products (Ochieng et al., 2015). Vacuum packaging combined with icing significantly increases product shelf life (Rajesh et al., 2002).

Applications of Vacuum Packaging

- A packaging commodity that requires 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.
- 4. Packaging with Controlled Release:** Controlled release packaging is a complex strategy that manages the release of chemicals that are included in packaging and has potential applications in food packaging via the managed dispersion of the active component. In CRP (controlled release packaging), 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. Intelligent Packaging Systems:** Technologies for intelligent food packaging monitor both the environment and the packed food in which it is kept. They could generate real-time food data on the safety and quality, which might help with food borne disease prevention (Yousefi et al., 2019). In contrast to active packaging, intelligent packaging does not instantly extend the shelf life of foods. Instead, they educate those involved in the food supply chain on food safety. 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).

- 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, colorimetric 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).
- 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).Consumers may be informed about potential food safety risks such as microbial growth, protein denaturation, or emulsion breakup using information about temperature abuse.
- Freshness indicators:** The freshness indicator's job is to pinpoint the chemical and microbial changes that lead to food decomposition. Based on naturally occurring amines and hydrogen sulphide (H₂S), which is formed during meat rotting, freshness indicators in meat products may be developed(Yousefi et al., 2019).

Table 2: Freshness Indicator Application

Analysed Property	Identification	Reference
Meat	Food spoilage by the release of amines and hydrogen sulphide	(Y. Zhang <i>et al.</i> , 2019)
Seafood	To identify microbial spoiling by release of volatile substance	(Morsy <i>et al.</i> , 2016)
Fruits	Identifies ripeness based on release of ethylene	(Kalpana <i>et al.</i> , 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).

- **RFID:** The food supply chain uses radiofrequency identification (RFID) tags to track the movement of food products. They can be used to automate processes, however they are not often utilised to gather information on food's nutritional worth, 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. The use of RFID tags to acquire information about food quality is uncommon, it is crucial to remember that (Bibi et al., 2017). In addition to regulating vegetable maturity, CO₂ and O₂ sensors were added to RFID labels to enhance the security and calibre of dairy goods (Wu et al., 2020).
- **Barcode:** A parallel series of readable bars and gaps is known as a barcode. 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 (Sohail et al., 2018).

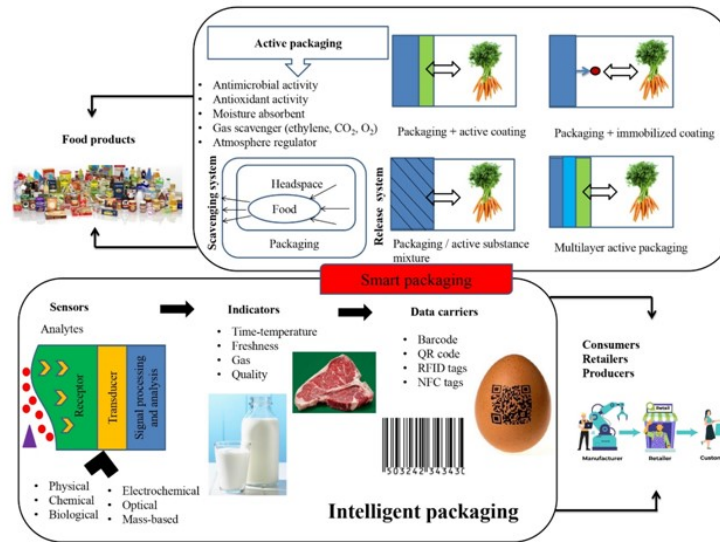


Figure 3: Smart Packaging

6. 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. These sensors also identify the gases that are released by spoiled food. When meat is spoiled, it releases NH_3 , ethanol, and H_2S 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 help in identifying the quality of food and also it can detect harmful organisms that cause 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 they contain 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.

VII. 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.

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. Bio-based polymers

have been categorised into three main groups depending on their origin and method of manufacturing. Directly derived polymers from biomass

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

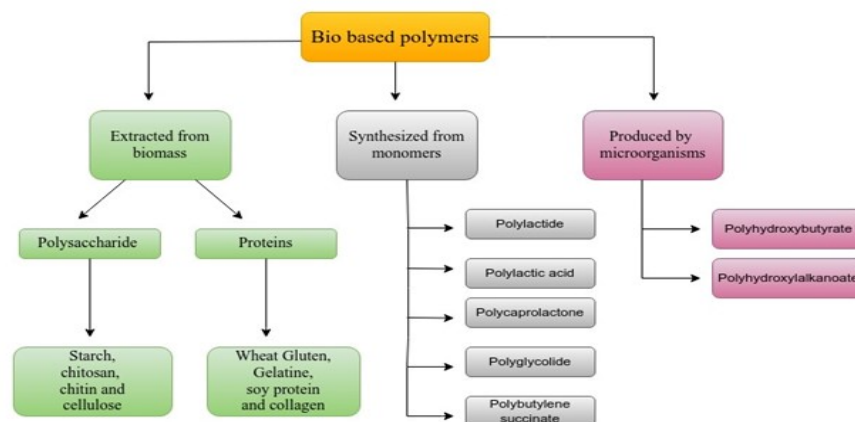


Figure 4: Bio based Food Packaging Materials

- 2. Directly Derived Polymers from Biomass:** These polymers come from marine and agricultural resources, and they possess a high degree of intramolecular connection and crystallinity.
- 3. Directly Derived Polymer from Microbes:** These microorganism-produced polymers are members of the polyhydroxy alkanolate 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).
- 4. Food Packaging Bio Adhesives:** 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. 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).

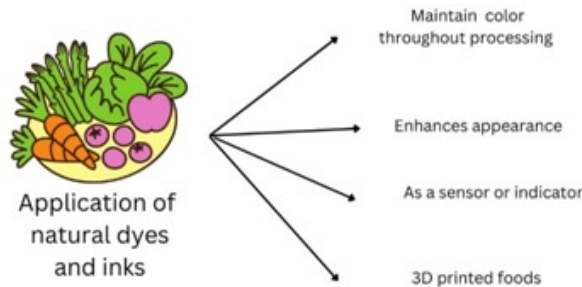


Figure 5: Application of Natural Dyes and Inks in Food Industries

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. When used as a 3D printer, the natural dye functions as an antioxidant and antimicrobial (Phan et al., 2021).

- 6. 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. Pouches, Coatings, sheets and, edible films are all examples of edible packaging materials. Although the initial three are separate structures that can be applied to food or sealed into bags and surface food is covered with a minimal amount of edible coating. (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).

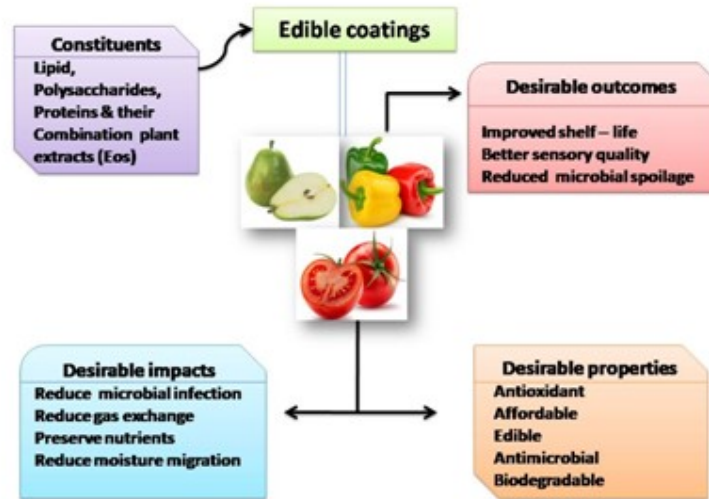


Figure 6: Edible Coating

The following categories apply to edible packaging materials:

- Materials acquired directly from organic sources, such as those obtained from aquatic, agricultural, and animal sources
- Polysaccharides and other active compounds are derived from genetically engineered microorganisms.
- Chemically generated materials such as surfactants, plasticizers, and other active compounds.

Furthermore, the made from proteins edible coating has excellent physical and barrier abilities against oil, air, and odour. The resistance against water-based vapours, on the other hand, is limited. Collagen gained the most attention in the manufacture of edible films. Polysaccharide-based films may help in extending the time of ripening and increase the duration of storage of coated foods (Raajeswari & Pragatheeswari, 2019). Shellac serves as an edible coating for sweets and food that is fresh. Composite materials are made up of edible substances that have been blended together to remove flaws. With a mix of citrus essential oil and grape extracts from seeds, active biodegradable films made of maize starch and chitosan have been produced.

VIII. APPLICATIONS OF MODERN PACKAGING TECHNOLOGIES

1. **Vegetables and Fruits:** In 2021, India showed the potential to become an exporter with \$750.7 million worth of fruits and vegetables. However, since these items are perishable, careful inside packing is required to retain freshness and assure that they will last (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. Humidity, oil content and climate are all significant factors in reducing the consequences of dangerous microorganisms. Proper handling and

handling, especially during transportation, is important to prevent microbial contamination (Pant & Thielmann, 2018).

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 <i>et al.</i> , 2020)
2	Tomato	Triticale films with KMnO ₄	After 21 days of storage slows the ripening of cherry tomatoes.	(Aragüez <i>et al.</i> , 2020)
3	Grapes	Edible films	improves the fresh green grapes' postharvest shelf life for a period of 21 days	(S. Kumar <i>et al.</i> , 2019)
4	Avocado	RFID Tag	Monitors ripening	(Occhiuzzi <i>et al.</i> , 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). Gas change is essential in vegetables and fruit packing because ethylene, a phytohormone that drives fruit ripening, may damage product quality during storage and export. The ethylene absorbers that are inserted in packaging to increase the preservation duration of vegetables and fruits that include apples, kiwis, apricots, bananas, mangoes, tomatoes, and avocados are alumina, potassium permanganate, and silica. (Murmu & Mishra, 2018).

- 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).

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 <i>A. parasiticus</i> and the generation of Aflatoxins.	(Qian <i>et al.</i> , 2021)
2	Sponge Cake	Nanocomposite emulsion film	Suppresses fungus development and keeps the cake's chemical and organoleptic properties.	(Sahraee <i>et al.</i> , 2020)
3	Pizza crust	Sachets of allyl isothiocyanate	It suppresses the production of Aflatoxin.	(Qian <i>et al.</i> , 2021)
4	Bun	Active packaging	Increases 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 elimination of free oxygen from the packaging, as well as the inclusion of an antibacterial agent, leads to an increase in the shelf life of baked goods. The baked products can be preserved with quality with the help of both active and intelligent packaging.

- 3. Dairy and Dairy Products:** A nutritious diet is essential for overall good health and wellness, and dairy is both nutritious and delicious. 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).

The greatest method for extending the shelf life and reducing contamination of milk and dairy products is smart packaging technology, which makes use of packaging materials that are antibacterial, antioxidant, and oxygen scavengers. 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).

Table 5: Modern Food Packaging Application for Dairy and Dairy Products

	Food item	Packaging type	Application	Reference
1	Cheese	Smart oxygen sensors	cheese quality level of deterioration was extended	(Deshwal <i>et al.</i> , 2021)
2	Butter	Chitosan-TiO ₂ and chitosan-Ag/TiO ₂ active papers	Clarified butter had a shelf life of up to six months	(Apjok <i>et al.</i> , 2019)
3	Yogurt	Natamycin-grafted films	extends the duration of storage of yoghurt to 23 days	(Anari <i>et al.</i> , 2022)
4	Paneer	Edible film made of essential oils	Increased shelf life	(Karunamay <i>et al.</i> , 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).Antibacterial properties of carbon dioxide gas boost milk preservation duration and quality(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 makinga profit from it.

- 4. Fresh Produce and Meat Products:** 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.

Oxymyoglobin may oxidise further to create metmyoglobin over time, causing 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)

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 <i>et al.</i> , 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 <i>et al.</i> , 2019)
5	Pork	pH-sensitive packaging films	Pork freshness was monitored	(Qin <i>et al.</i> , 2019)

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

IX. 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 increased food safety and shelf life. Traditional preservation, on the other hand, is based on centuries-old practises that are efficient at 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 recognizing the fundamentals, applications, benefits, and drawbacks of both traditional and modern food packaging and preservation techniques.

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