Novel Food Packaging Techniques

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Introduction

Novel food packaging techniques refer to innovative methods and technologies developed to protect and preserve food products. These techniques go beyond traditional packaging approaches and aim to enhance food safety, extend shelf life, improve convenience, and reduce environmental impact. Novel food packaging technologies have emerged in response to consumers' increasing desire for convenient, ready-to-eat, flavourful, and minimally processed food products that have a longer shelf life and maintain their quality. Additionally, modern retail practices and evolving lifestyles have driven the development of innovative packaging methods that do not compromise food safety and quality. The rapid growth of novel packaging in the food industry is fuelled by the increasing consumption of packaged foods, the demand for ready-made meals (such as microwaveable dishes), and the popularity of smaller-sized food packages. Another significant driver for innovative food packaging is the rising concern over foodborne microbial outbreaks, which necessitates packaging solutions with antimicrobial properties while preserving food quality.

Innovations in packaging began with the introduction of electrically driven packaging machinery, followed by the development of metallic cans, aseptic packaging, flexible packaging, Aluminium foils, and flexographic printing. Furthermore, the introduction of various materials such as polyester, polypropylene, and ethylene vinyl alcohol polymers led to a shift from traditional metal, paperboard, and glass packaging to plastic and flexible packaging. In the 20th century, advancements in packaging technology gave rise to intelligent or smart packaging and active packaging, which includes components like oxygen scavengers, antimicrobial agents, and aroma/odour absorbers.

1. Reduced Oxygen Packaging

"Reduced Oxygen Packaging" (ROP) refers to a food packaging method that involves:

(i) Reducing the oxygen content within a package through one or more of the following techniques: removing oxygen, displacing oxygen with another gas or a combination of gases, or otherwise controlling the oxygen levels to a point below what is typically found in the surrounding air (which is typically at 21 % oxygen content; thus, ROP involves maintaining oxygen levels below 21 %).

(ii) A process applied to foods that have specific hazards related to the growth of *Clostridium botulinum* and *Listeria monocytogenes*, which need to be controlled in the final packaged form to ensure food safety.

1.1 Typical applications for ROP include:

1.1.1 Vacuum packaging

Vacuum packaging involves the removal of air from the package and the application of a hermetic seal. The air removal creates a vacuum inside the packs and lack of O_2 in packages may minimise the oxidative deteriorative reactions and aerobic bacterial growth. Vacuum packaging can considerably extend the viable shelf life of many cooked foods. The use of vacuum packaging, in gas impermeable and heat stable materials, has many advantages, which include; no or low risks of post pasteurisation contamination, ease of handling, Inhibition of growth of aerobic spoilage organisms and inhibition or slowing of deleterious oxidative reactions in the food during storage due to oxygen barrier properties of the packaging material.

There are number of criteria required for the films used for vacuum packaging in large scale production methods. These requirements include: high durability, ie. ability to withstand considerable mechanical stresses during packaging, handling and transport, retention of flexibility even at low temperatures (-2 to 4°C) to enable satisfactory handling in the packaging and refrigeration rooms, ability to withstand heating to at least 150 °C without structural damage, leaching of potentially toxic plastics or plasticisers, impermeability to liquids, including oils and fats and macromolecules, impermeability to gases, in particular oxygen, so that oxidative deterioration of the packaged food stuffs is limited or inhibited, manufactured from non-toxic, food acceptable, odourless materials and must be able to create airtight durable heat seals to close packs. Many of these criteria have been met by a range of materials mostly multilaminated plastics. Vacuum packed foods maintain their freshness and flavor 3-5 times longer than with conventional storage methods, because they don't come in contact with oxygen. Foods maintain their texture and appearance, because microorganisms such as bacteria mold and yeast cannot grow in a vacuum. Freezer burn is eliminated, because foods no longer become dehydrated from contact with cold, dry air. Moist foods won't dry out, because there's no air to absorb the moisture from the food. Dry, solid foods, won't become hard, because they don't come in contact with air and, therefore, can't absorb moisture from the air. Foods that are high in fats and oils won't become rancid, because there's no oxygen coming in contact with the fats, which causes the rancid taste and smell.

Fig. 1 Vacuum packaging machine and Vacuum-packed fish

1.1.2 Modified Atmospheric packaging

Fresh fish is highly susceptible to spoilage from post mortem autolysis and microbial growth. The high ambient temperature of our country favours rapid growth of microorganisms. Presently ice and mechanical refrigeration are the most common means of retarding microbial and biochemical spoilage in freshly caught seafood during distribution and marketing. However, as ice melts it tends to contaminate fish accelerating spoilage and reduces shelf life. Modified atmosphere packaging, a technologically viable method has been developed as a supplement to ice or mechanical refrigeration to reduce the losses and extend the storage life of fresh seafood products. In modified atmosphere packaging air is replaced with different gas mixtures to regulate microbial activity and /or retard discolouration of the products. The proportion of each component gas is fixed when the mixture is introduced into the package; however, no control is exercised during storage. The composition of the gas mixture changes from its initial composition as a result of chemical, enzymatic and microbial activity of the product during storage. It is primarily the enrichment of Carbon dioxide in the storage atmosphere as a means of controlling microbial growth, which results in the extension of shelf life of products. Carbon dioxide lowers the intra and extracellular pH of tissues and possibly that of microorganisms. Further it may affect the membrane potential of microorganisms and influence on the equilibrium of decarboxylating enzymes of microorganisms. The gases normally employed are carbon dioxide, mixtures of carbon dioxide and nitrogen, carbon dioxide and oxygen and carbon dioxide, oxygen & nitrogen with the sole objective to extend the shelf life of the product beyond that obtained in conventional refrigerated storages. Inhibition by Carbon dioxide manifests in an increased lag phase and a slower rate of growth of microorganisms during logorathmic phase. Inhibition by Carbon dioxide was found to be more effective when the product was stored at the lowest range of refrigerated temperatures. Packaging materials generally employed for this purpose are flexible films of nylon/surylyn laminates, PVC moulded trays laminated with polythene, polyester/low density polythene film etc. The use of high barrier film along with MAP that contains CO_2 effectively inhibits bacterial growth during refrigerated storage of packaged fresh fishery products.

The composition of the gas mixtures used for MAP of fresh fish varies, depending upon whether the fish in the package is lean or oily fish. For lean fish, a ratio of 30% Oxygen, 40% Carbon dioxide, 30% Nitrogen is recommended. Higher values of Carbon dioxide are used for fatty and oily fish with a comparable reduction in level of Oxygen in the mixture leading to 40-60% Nitrogen. By excluding oxygen, the development of oxidative rancidity in fatty fish is slowed. On the other hand, oxygen can inhibit the growth of strictly anaerobic bacteria like *Clostridium botulinum* although there is a very wide variation in the sensitivity of anaerobes to Oxygen. It is also seen that inclusion of only some Oxygen with Nitrogen or Carbon dioxide will not prevent botulism with absolute certainty.

Fig. 2 Modified atmosphere packaging equipment and Gas composition analyser

1.1.3 Controlled Atmosphere Packaging (CAP)

It is a method of packaging food products in a modified atmosphere to extend their shelf life and maintain their quality. In CAP, the composition of gases within the package is carefully controlled to create an optimal environment for the specific food product.

The main objectives of CAP are to control the levels of oxygen, carbon dioxide, and sometimes nitrogen within the package. These gases are selected based on the specific needs of the food product and its susceptibility to spoilage factors.

The benefits of CAP include:

1. Extended Shelf Life: By controlling the atmosphere within the package, CAP can slow down the growth of spoilage microorganisms and enzymatic reactions that cause food deterioration, thereby extending the product's shelf life.
2. Maintained Quality: CAP helps preserve the sensory attributes, colour, texture, and nutritional content of the food by creating an environment that minimizes oxidative reactions and maintains optimal conditions for the product.
3. Reduced Need for Preservatives: With controlled gas composition, CAP can reduce the reliance on chemical preservatives, allowing for a more natural and cleaner label approach to food preservation.

The specific gas composition and ratios used in CAP depend on the type of food product being packaged. For example, some fruits and vegetables benefit from a lower oxygen level and higher carbon dioxide level to slow down ripening and preserve freshness, while certain meats may require a higher oxygen level to maintain the desired colour. It's important to note that CAP requires specialized packaging materials, such as barrier films or trays with gas-permeable properties, to maintain the desired gas composition and prevent gas leakage. Proper sealing and storage conditions are also critical to ensure the effectiveness of CAP. The selection and implementation of CAP should be based on scientific research, industry guidelines, and regulatory requirements to ensure food safety and maintain product quality throughout the supply chain.

1.1.4 Cook chill packaging

Cook chill is a food preservation method that involves cooking food to the desired temperature, rapidly cooling it, and then packaging it for later use. The process helps maintain the food's quality, flavour, and safety while extending its shelf life.

Cook chill packaging typically involves the following steps:

- Cooking: The food is cooked thoroughly to the appropriate temperature to ensure it is safe to consume.
- Rapid Cooling: After cooking, the food is rapidly chilled using specialized equipment, such as blast chillers or cold-water baths. Rapid cooling inhibits bacterial growth and prevents the food from spending too much time in the temperature danger zone where bacteria can multiply quickly.
- Packaging: Once the food has been cooled, it is portioned and packaged in airtight containers, such as vacuum-sealed bags or sealed trays. The packaging helps maintain the food's freshness and prevents contamination.
- Storage: The packaged food is then refrigerated or frozen until it is ready to be consumed. The controlled temperature storage further extends the shelf life of the cooked food.

1.1.5 Sous Vide Packaging

Sous vide is a cooking technique that involves vacuum-sealing food in a bag and cooking it at a precisely controlled low temperature in a water bath. This method ensures consistent and evenly cooked food with enhanced flavours and textures.

Sous vide packaging typically includes the following steps:

- Vacuum Sealing: The food, along with any desired seasonings or marinades, is placed in a vacuum-sealed bag. The bag is sealed tightly to remove any air and create an airtight environment for cooking.
- Temperature Control: The sealed bags of food are submerged in a precisely heated water bath, which is set to a specific temperature based on the desired doneness of the food. The water bath is typically maintained at a lower temperature than traditional cooking methods.
- Cooking Time: The food is cooked in the water bath for an extended period, allowing it to slowly reach the desired internal temperature while retaining its moisture and flavour.
- Finishing: After the sous vide cooking process, some foods may be finished

with additional steps such as searing, grilling, or browning to add texture and colour.

2. Active Packaging

Active packaging is an innovative concept that can be defined as 'a type of packaging that changes the condition of the packaging and maintains these conditions throughout the storage period to extend shelf-life or to improve safety or sensory properties while maintaining the quality of packaged food'. Active packaging (AP) performs some desired role other than providing an inert barrier between the product and external conditions and combines advances in food technology, bio-technology, packaging and material science, in an effort to comply with consumer demands for 'fresh like' products. This involves incorporation of certain additives into the packaging film or within packaging containers with the aim of maintaining and extending product shelf life. Active packaging technique is either scavenging or emitting systems added to emit (e.g., N_2, CO_2, ethanol, antimicrobials, antioxidants) and/or to remove (e.g., O_2, CO_2, odour, ethylene) gases during packaging, storage and distribution. In case of a gas-scavenging or emitting system, reactive compounds are either contained in individual sachets or stickers associated to the packaging material or, more recently, directly incorporated into the packaging material. Major active packaging techniques are concerned with substances that absorb oxygen, ethylene, moisture, carbon dioxide, flavours/odours and those which release carbon dioxide, antimicrobial agents, antioxidants and flavours. The most important active packaging concepts for fishery products include O_2 scavenging, CO_2 emitters, moisture regulators, antimicrobial packaging concepts, antioxidant release are discussed here.

2.1 Oxygen (O_2) scavenger

Fish products are highly susceptible to oxygen as it leads to the growth of aerobic microorganisms and oxidation which causes undesirable colour changes (e.g., discolouration of pigments such as myoglobin, carotenoids), off-odours and flavours (e.g., rancidity as a result of lipid oxidation) and leads to loss of nutrients (e.g., oxidation of vitamin E, β-carotene, ascorbic acid) which adversely affects the quality. Therefore, control of oxygen levels in food package is important to limit the rate of such deteriorative and spoilage reactions in foods. Although O_2- sensitive foods can be packed appropriately using modified atmosphere packaging (MAP) or vacuum packaging, these technologies do not always remove O_2 completely. Moreover, the O_2 that permeates through the packaging film cannot be removed by these techniques. By use of an O_2-scavenger, which absorbs the residual O_2 after packaging, quality changes of O_2-sensitive foods associated with low residual oxygen levels can be minimized. O_2 scavengers were first commercialized in the late 1970s by Japan's Mitsubishi Gas Chemical Company (Ageless®). O_2 scavengers are able to eliminate oxygen contained in the packaging headspace and in the product or permeating through the packaging material during storage. O_2 scavengers are efficient in preventing discolouration of fresh and cured fish, rancidity problems, mould spoilage of intermediate and high moisture products or oxidative flavour changes. O_2 scavenging concepts are mainly based on iron powder oxidation, ascorbic acid oxidation, photosensitive dye oxidation, enzymatic oxidation (e.g., glucose oxidase and alcohol oxidase), unsaturated fatty acids (e.g., oleic or linolenic acid), rice extract or immobilized yeast on a solid substrate. Structurally, the oxygen scavenging component of a package can take the form of a sachet, label or film (incorporation of scavenging agent into the packaging film, which avoids the accidental consumption of sachet), card, closure liner or concentrate.

2.2 CO_2-emitter

The method of preserving food products using CO_2 is not new. Modified atmosphere packaging which mainly employs the gases like CO_2, N_2 and O_2 has been in use for extending the freshness of fish products since many decades. The high CO_2-levels (10-80 %) are desirable for moist food products like fish, shellfish and meat products which inhibit surface microbial growth and thereby extend shelf-life. The overall effect of CO_2 is to increase both the lag phase and the generation time of spoilage microorganisms. Over the years this has been achieved by modified atmosphere packaging, in which a package is flushed with a mixture of gases including carbon dioxide at sufficient levels. However, the concentration of CO_2 within the package will change due to the partial dissolution of CO_2 in to the product and permeability through the packaging film. Normally, the permeability of carbon dioxide is 3–5 times higher than that of oxygen in most plastic films, so it must be continuously produced to maintain the desired concentration within the package. A carbon dioxide generating system can be viewed as a technique complimentary to MAP to overcome the drawbacks. The potential of CO_2 in MAP and more recently generation of CO_2 inside the packaging system have been explored in relation to a number of commodities for their successful preservation. Such systems are based on sodium bicarbonate, ferrous carbonate, ascorbate, citric acid etc. Sodium bicarbonate, when used together with ascorbic acid or citric acid in the presence of sufficient moisture generates CO_2. This technique is very simple and economical as it does not require any costly equipment and pure gases.

2.3 Moisture regulator

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

2.4 Antimicrobial packaging

A significant portion of fish deterioration is related to microbial contamination and development, which shortens food shelf life and raises the possibility of food borne illness. The use of antimicrobial chemicals or salts as well as heat processing, drying, freezing, refrigeration, irradiation, and MAP are traditional means of protecting fish from the effects of microbial development. However, some of these methods can't be used on products made from fresh fish because they change the freshness of the fish. A rapidly growing active packaging, particularly for fish and poultry items, is antimicrobial packaging.

Antimicrobial films primarily work by releasing antimicrobial substances into food, which prolongs the lagged phase and shortens the growth phase of microbes, hence extending shelf life and maintaining product quality and safety. Antimicrobial agents may be surface modified, immobilised, coated, integrated, or immobilised onto packaging materials to give antimicrobial activity. In order to prevent the growth of bacteria on food surfaces, promising active packaging solutions include antimicrobial agents into the materials used to package food. The preservative is liberated from the active substance and acts directly when it comes into touch with a moist food or a food that has a liquid-like consistency. In both situations, the system's goal is to prolong the packed food's shelf life by preventing microbial development and maintaining its qualities. Acid anhydride, alcohol, bacteriocins, chelators, enzymes, organic acids, and polysaccharides are only a few of the classes of antimicrobials. In addition to these, chitosan and other derivatives from plants and fishing waste can be used in the packaging system as antimicrobials.

2.5 Antioxidant release

Antioxidants are frequently employed as food additives to enhance lipid oxidation stability and extend shelf life, mostly for dried goods and O_2-sensitive foods like fish due to their high content of unsaturated fatty acids. Antioxidants can also be combined into plastic films to stabilise the polymer and prevent deterioration. BHT, a butylated hydroxytoluene, is frequently used in packaging films as an antioxidant. BHT's propensity to accumulate in human adipose tissue, however, has raised some questions about the physiological implications of use. As a result, less artificial antioxidants are being used in interaction with food. Therefore, it is preferable to use natural antioxidants that are safe. The most prevalent natural antioxidants are vitamins E and C, and researchers are still exploring how to incorporate them into polymer films to have antioxidative benefits. Vitamin E has great solubility in polyolefins and is stable during processing. In addition to these, research is being done on the use of natural antioxidants derived from plant and animal sources as packaging for antioxidants.

3. Active Packaging Systems with Dual Functionality

The employment of multiple function active systems is a more advanced method of increasing the life stability of packaged goods utilising active packaging systems. For instance, the storage of packaged foods is greatly increased when oxygen scavengers are combined with carbon dioxide and/or antibacterial / antioxidant releasing systems. When oxygen is removed from packages using an O_2 scavenger alone, a partial vacuum is created, which could cause flexible packaging to collapse. In addition, when a package is flushed with a gaseous mixture that includes carbon dioxide, the CO_2 dissolves in the product, creating a partial vacuum, causes the permeation of CO_2 through the packaging film. However, in order to prevent the growth of surface microbes and increase shelf life, high CO_2 levels are required. The self-working devices, which absorb O2 and generate enough CO_2, will be promising in such situations for increasing the shelf life of goods, particularly fishery items. In order to extend the shelf-life of various food systems, ICAR-CIFT has developed the technology for these active packaging systems.

4. Intelligent Packaging

Intelligent packaging detects certain characteristics of food it contains or the environmental conditions in which it is placed and notifies the people of the state of these properties. The attributes of intelligent packaging could be employed to check the efficiency and reliability of active packaging systems. Intelligent packaging has been described as ‘packaging technology that can monitor the state of packaged foods to issue details about the quality of the packaged food during transport and storage’. A variety of indicators such as temperature, time temperature, pack integrity, microbial growth, product authenticity and freshness are of interest to the fish packaging industry.

4.1 Time-temperature indicators

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

4.2 Leakage indicator

The development of improved methods to determine food quality such as freshness, microbial spoilage, oxidative rancidity or oxygen and/or heat induced deterioration is extremely important to food manufacturers. In order to maximise the quality and safety of foodstuffs, prediction of shelf-life, based on standard quality control procedures is normally undertaken. Replacement of such time-consuming and expensive quality measurements with rapid, reliable and inexpensive alternatives has led to greater efforts being made to identify and measure chemical or physical indicators of food quality. Determination of indicator headspace gases provides a means by which the quality of a fish and meat product and the integrity of the packaging in which it is held can be established rapidly and inexpensively. One means of doing so is through the intelligent packaging incorporating gas sensor technology for sensing the oxygen and CO_2, as these two are the most commonly used gases. The monitoring of these gases in the package helps in establishing the food quality. The profiles of oxygen and carbon dioxide can change over time and are influenced by product type, respiration, packaging material, pack size, volume ratios, storage conditions, package integrity etc. A number of analytical techniques are available to monitor gas phases in MAP products. Instrumental techniques such as GC and GC/MS require breakage of package integrity and are time-consuming and expensive. Portable headspace oxygen and/or carbon dioxide gas analysers use 'minimally destructive' techniques (packages can be re-sealed) but tend not to be applicable to real-time, on-line control of packaging processes or large-scale usage. An optical sensor approach offers a realistic alternative to such conventional methods. They can be used as a leak indicator or to verify the efficiency of O_2- scavenger, CO_2 emitter or MAP systems. Most of these indicators assume a colour change as a result of a chemical or enzymatic reaction. The most common redox dye used for leak indicators is methylene blue.

4.3 Freshness indicators

An ideal indicator for the quality control of packaged food products should indicate the spoilage or lack of freshness of the product, in addition to temperature abuse or package leak. The information provided by intelligent packaging systems on the quality of food products may be either indirect (e.g., deviation from storage temperature and changes in packaging O_2/CO_2 concentration may imply quality deterioration through established correlation) or direct. These freshness indicators are based on the detection of volatile metabolites produced during ageing of foods, such as CO_2, diacetyl, amines, ammonia and hydrogen sulphide. Freshness indicators provide direct product quality information resulting from microbial growth or chemical changes within a food product. Microbiological quality may be determined through reactions between indicators included within the package and microbial growth metabolites. The chemical detection of spoilage of fish and the chemical changes in fish during storage provide the basis for which freshness indicators may be developed based on target metabolites. Total volatile nitrogenous compounds and biogenic amines such as histamine, putrescine, tyramine and cadaverine have been implicated as indicators of fish product decomposition. As the biogenic amines are toxic compounds and they cannot be detected sensorily, the development of effective amine indicators would be beneficial. Hydrogen sulphide, a breakdown product of cysteine, with intense off-flavours and low threshold levels is produced during the spoilage of fish and shellfish by a number of bacterial species. It forms a green pigment, sulphmyocin, when bound to myoglobin and this pigment can be used as a basis for the development of a freshness indicator in red meat fishes. Normally, the freshness indicators are incorporated into the packaging film, which reacts with volatile amines and other indicating agents produced during the storage of fish and other seafoods, and the freshness is indicated by a colour change.

5. Other Novel Food Packaging Methods

5.1 Edible Packaging: Edible packaging materials are designed to be consumed along with the food, reducing waste and enhancing convenience. These materials can be made from edible films or coatings derived from natural sources such as seaweed or starch. Edible packaging is particularly beneficial for single-serving products or items that require individual portioning.

5.2 Anti-counterfeiting Packaging: To combat food fraud and ensure product authenticity, advanced packaging techniques may incorporate features like tamper-evident seals, holograms, or QR codes for verification.

5.3 Nanotechnology in Packaging: Nanotechnology involves manipulating matter at the nanoscale to create novel materials and structures. Nanoparticles and nanocomposites can be incorporated into food packaging to provide improved barrier properties, antimicrobial effects, and enhanced mechanical strength.

5.4 Sustainable Packaging: As environmental concerns grow, sustainable packaging techniques are gaining popularity. This includes using eco-friendly materials, optimizing package sizes to minimize waste, and exploring biodegradable or compostable packaging options.