

Edible Packaging: The Next Big Step Towards a Plastic-Free Food Industry

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Packaging is an essential component of the modern food supply chain. It protects food against contamination, physical damage, oxidation, and moisture changes while facilitating transportation, storage, and distribution. Conventional plastic materials have become widely used because of their versatility, lightweight nature, low cost, and effective barrier properties. Nevertheless, the accumulation of plastic waste has raised significant environmental concerns and encouraged the development of alternative packaging technologies. Edible packaging is gaining attention as one potential solution to this challenge. It uses edible substances to create protective films, coatings, wraps, and other structures that can be consumed along with the food or used as a functional layer on its surface. The technology aims to integrate food protection with more efficient material use and reduced packaging waste. According to Petkoska et al. (2021), edible packaging research increasingly focuses on sustainable materials, active packaging functions, and the incorporation of functional compounds. However, edible packaging is not suitable for every food product, and its environmental benefits depend on the material, manufacturing process, and intended application. The central challenge is therefore to develop packaging that provides reliable food protection while meeting the technical, economic, environmental, and safety requirements of the food industry.



Concept and Types of Edible Packaging

Edible packaging generally takes two major forms: edible films and edible coatings.

Edible Films

Edible films are thin, pre-formed layers prepared from edible film-forming materials. They can be used as wraps, separators, sachets, or protective layers around selected food products. Depending on their formulation, some films may dissolve in water or be consumed with the food. For example, starch-based or protein-based films may be developed for selected dry foods, confectionery, or individual food portions. Their suitability depends on flexibility, tensile strength, permeability, and compatibility with the product.



Edible Coatings

Edible coatings are applied directly to food surfaces through methods such as dipping, spraying, or brushing. After application, the coating forms a thin layer that can influence moisture loss, gas exchange, oxidation, and other quality-related processes. Fruit coatings are an important area of research because fresh produce continues to respire and undergo physiological changes after harvesting. A suitable coating may help slow certain deterioration processes and maintain quality during storage. Unlike edible films, which are formed separately before application, coatings are deposited directly onto the food surface. The distinction is important when selecting an appropriate manufacturing process and evaluating packaging performance (Suhag et al., 2020).

Materials Used in Edible Packaging

The functional performance of edible packaging depends on the composition of the material and its interactions with food and the surrounding environment.

Polysaccharide-Based Materials

Polysaccharides are widely investigated because they can form films and coatings from renewable biological resources. Common examples include starch, pectin, alginate, cellulose derivatives, and selected gums. Starch is attractive because of its availability, relatively low cost, and film-forming ability. Pectin can be obtained from suitable plant materials, including citrus peel and apple pomace, while alginate is commonly associated with seaweed-derived materials. These polymers can provide useful structural and gas-barrier properties under appropriate conditions. However, many polysaccharide films are sensitive to moisture, which can reduce their mechanical strength and barrier performance at high humidity.



Protein-Based Materials

Proteins such as gelatin, whey protein, casein, soy protein, and zein have also been studied for edible film development. Protein-based films can provide good film-forming properties and useful barriers to oxygen under suitable conditions. Their performance depends on protein composition, processing conditions, plasticizer concentration, and environmental humidity. For instance, soy protein films may be investigated for selected food applications, while whey protein films offer opportunities for research involving dairy-derived materials. Potential allergens and the suitability of ingredients for their intended use must be considered.

Lipid-Based Materials

Lipids, including selected waxes, fatty acids, and oils, can improve resistance to moisture transfer when incorporated into suitable edible coatings or composite films. These materials are particularly relevant to fresh fruits and vegetables, where water loss may cause shrivelling, weight reduction, and deterioration of appearance. However, lipid-based materials alone may have limited mechanical strength. Their combination with polysaccharides or proteins can help produce materials with a more balanced set of properties.

Composite Edible Materials

Composite films combine two or more material classes to improve overall functionality. For example, a polysaccharide matrix may be combined with a lipid component to improve moisture resistance, while a protein-polysaccharide combination may be investigated to improve structural integrity. The design of such materials requires careful optimization because the addition of one component can improve one property while negatively affecting another. Devi et al. (2024) discuss the role of lipid incorporation in modifying the properties and applications of biopolymer-based edible films and coatings.

Manufacturing Technologies

Edible films and coatings can be manufactured using several methods, depending on the formulation, intended use, and production scale.

Solvent Casting

In solvent casting, the film-forming ingredient is dispersed or dissolved in a suitable medium. A plasticizer, such as glycerol or sorbitol, may be added to improve flexibility. The solution is then spread over a flat surface and dried under controlled conditions. After drying, the film is removed and evaluated for thickness, tensile strength, elongation, solubility, and barrier properties. Casting is widely used in laboratory research because it allows researchers to control formulation variables and prepare films for experimental testing. However, drying time and uniformity can become challenges during industrial scale-up.

Extrusion

Extrusion is a processing technique that uses heat, pressure, and mechanical mixing to transform suitable materials into continuous film structures. It has potential advantages for large-scale production because continuous processing can improve manufacturing efficiency. However, the material must tolerate the selected processing conditions without losing its required functionality.

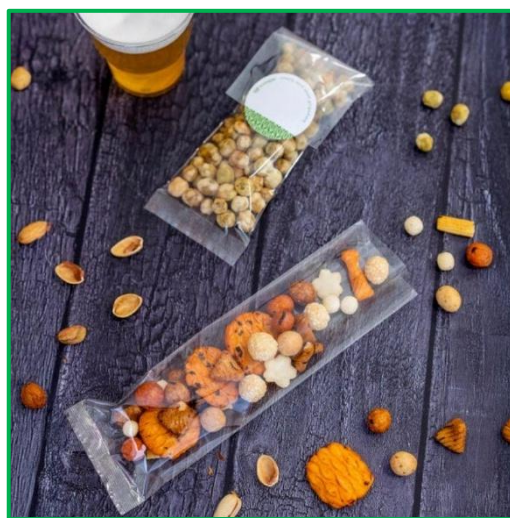
Dipping and Spraying

Dipping involves immersing a food product in a coating solution, followed by draining and drying or setting. Spraying distributes a coating solution over the product surface. Dipping is relatively straightforward for laboratory experiments, while spraying can offer advantages for uniform application and industrial processing when properly controlled. The selection of a deposition method depends on the food's surface characteristics, coating viscosity, desired thickness, drying requirements, and production speed (Suhag et al., 2020).

Applications in the Food Industry

Fruits and Vegetables

Fresh fruits and vegetables are promising candidates for edible coatings because they continue to respire and lose moisture after harvesting. Appropriately formulated coatings may help reduce moisture loss, modify gas exchange, maintain appearance, and delay selected quality changes. Their effectiveness varies with the fruit or vegetable, maturity, storage temperature, relative humidity, and coating composition. Research on fresh produce should evaluate changes in weight loss, firmness, colour, respiration, microbial quality, sensory properties, and shelf life rather than assuming that a coating will always improve preservation.



Bakery Products

Edible films may be used as separators or protective layers for selected bakery products. Depending on their formulation, they may help control moisture migration or reduce surface drying. However, different bakery products have different preservation requirements. A film suitable for a dry biscuit may not be appropriate for a moist cake because water migration can alter texture and product stability.

Dairy Products

Selected edible coatings have been investigated for cheese and other dairy products to help control moisture loss, oxidation, and surface quality changes. Nevertheless, dairy foods may require strong barriers against contamination and carefully controlled storage conditions. Edible coatings must therefore be evaluated alongside established food safety and packaging practices.

Confectionery and Instant Foods

Edible films and sachets may be developed for selected confectionery products, powdered ingredients, seasonings, and portion-controlled food ingredients. Water-soluble films are particularly interesting where the package is intended to dissolve during food preparation. Their performance depends on dissolution time, temperature, moisture sensitivity, ingredient compatibility, and safety.

Meat and Seafood

Edible films and coatings have been investigated as carriers for selected antimicrobial and antioxidant compounds in meat and seafood applications. Such systems may help manage oxidation and microbial deterioration when their effectiveness is established under appropriate storage conditions. They should not be treated as substitutes for refrigeration, hygienic handling, validated preservation processes, or required protective packaging.

Active Edible Packaging: Beyond Conventional Protection

An important development in edible packaging is the incorporation of functional ingredients into the film or coating matrix. Active edible packaging is designed to interact with the food or its immediate environment to help maintain quality. Depending on the formulation, it may contain suitable antioxidants, antimicrobial agents, or other functional compounds. For example, selected plant extracts are being investigated for their antioxidant or antimicrobial potential. However, the activity of a compound in a laboratory test does not necessarily demonstrate effective preservation in a real food system. Its concentration, stability, release behaviour, flavour impact, and safety must be assessed. Encapsulation technologies may also help protect sensitive ingredients and control their release. These approaches offer research opportunities in food preservation, but the safety and regulatory acceptability of each formulation must be established before commercial use (Petkoska et al., 2021). Intelligent packaging is a related but distinct technology. It provides information about product condition or storage history through indicators or sensors. Although edible materials may form part of an indicator system, the complete system is not necessarily edible.

Environmental Significance and Sustainability

The potential environmental benefits of edible packaging arise from its ability to reduce the use of conventional packaging materials in selected applications. First, edible coatings may reduce the need for an additional external wrapper when the coating provides adequate protection and the product can be handled safely. Second, edible films made from renewable resources may offer alternatives to packaging materials derived entirely from fossil resources. Third, suitable materials may be obtained from food-processing by-products, such as fruit pomace or selected agricultural residues. This approach could support resource recovery and add value to underutilized biomass. Fourth, edible coatings that maintain the quality of perishable foods may contribute to reducing food losses during storage and distribution. However, sustainability must be assessed across the entire life cycle. Agricultural inputs, water consumption, energy requirements, processing losses, transport, and end-of-life conditions can influence the environmental performance of an edible packaging system. Consequently, an edible material should not automatically be considered environmentally superior to conventional packaging. A life-cycle assessment comparing materials under equivalent food-protection conditions is necessary to establish the actual benefits.



Major Challenges to Commercialization

Despite continuing research, several challenges limit the widespread commercial adoption of edible packaging.

Moisture sensitivity: Many edible polymers are hydrophilic and absorb moisture, potentially weakening the film and reducing its barrier performance.

Mechanical properties: Some films have limited flexibility, tensile strength, or resistance to handling and may not withstand commercial distribution conditions.

Shelf-life protection: Edible materials may not provide sufficient barriers to oxygen, water vapour, light, or microorganisms for certain products.

Sensory acceptability: Packaging can affect flavour, aroma, colour, texture, and mouthfeel. Consumer acceptance depends on compatibility with the food.

Production costs: Raw-material processing, drying, specialized equipment, and quality control can increase manufacturing costs.

Food safety and regulation: Ingredients, processing aids, functional additives, and finished materials must meet applicable food safety requirements. Allergen management, microbiological quality, chemical purity, and intended conditions of use require particular attention.

Industrial scalability: Laboratory success does not guarantee commercial feasibility. Continuous production, uniform thickness, reproducible properties, storage stability, and economic performance must be demonstrated.

These challenges indicate that edible packaging development requires collaboration among food technologists, material scientists, packaging engineers, manufacturers, and regulatory specialists.