Discover Food

https://doi.org/10.1007/s44187-026-00841-z

Article in Press

The futuristic trend of edible and biodegradable food packaging, its impact and need: a review

Received: 15 May 2025

Accepted: 20 January 2026

Published online: 03 March 2026

Cite this article as: Wandhekar S., Kshirsagar R.B., Shaikh A.M. *et al.* The futuristic trend of edible and biodegradable food packaging, its impact and need: a review. *Discov Food* (2026). https://doi.org/10.1007/s44187-026-00841-z

Sangram Wandhekar, R. B. Kshirsagar, Ayaz Mukarram Shaikh, B. M. Patil, S. T. Shinde, B. S. Agarkar & Béla Kovacs

The Futuristic Trend of Edible and Biodegradable Food Packaging, Its Impact and Need: A Review

Sangram Wandhekar*[1,2,3], Kshirsagar R. B.[1], Ayaz Mukarram Shaikh[2,3*], B. M. Patil[1], S. T. Shinde[1], Agarkar B. S.[1], Bela Kovacs[2,3*]

[1]Department of Food Engineering, College of Food Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India (431 402).
(Email: sswandhekar77@gmail.com ; rajeshkshirsagar69@gmail.com ; bhanudas.95@gmail.com; sgreevshinde@gmail.com; agarkarbs207@gmail.com)

[2]Institute of Food Science, University of Debrecen, 138 Böszörményi St., 4032 Debrecen, Hungary.

[3]Doctoral School of Food Science & Nutrition, University of Debrecen, Böszörményi út 138, 4032 Debrecen, Hungary

(sangram.wandhekar@agr.unideb.hu , Ayaz.shaikh@agr.unideb.hu , Kovacsb@agr.unideb.hu)

Corresponding author: Béla Kovacs , Ayaz Mukarram Shaikh

Abstract

The demand for sustainable and eco-friendly packaging is increasing with the growing environmental concerns caused by single-use plastic packaging and utensils. To meet the changing demands of the market, including consumer preferences for healthy, high-quality food products, safety, and reduced environmental impact of plastic packaging, there is a need for innovations in the food packaging sector. Change towards sustainable and green packaging intends to reduce the environmental effects by incorporating edible or biodegradable materials, natural additives, utilizing plant parts and agricultural waste. The combination of active, intelligent and sustainable packaging technologies results in a multifunctional food-packaging system with no negative interactions

between components, signifying an important milestone toward a more sustainable future in the food sector. Sustainable packaging manufactured from natural, biodegradable materials offers benefits and reduces waste. In this paper negative impact of conventional packaging, need of alternative packaging, materials required for edible and biodegradable packaging, manufacturing processes, applications, suitability for various uses, regulations, challenges and opportunities are explored. The significance of edible and biodegradable packaging lies in its potential to transform the food industry. This innovative approach addresses the growing concerns about plastic pollution and food safety, making it a pivotal component of modern food packaging strategies.

Keywords: Packaging, Edible, Biodegradable, Sustainability, Pollution

1. Introduction

Packaging plays an important role in safeguarding food products from physical, chemical, and biological hazards, which helps to prevent spoilage, preserve quality, and extend the shelf life of commodity [1]. The primary function of packaging includes protection, preservation, safety and extension of food products shelf life during transportation, storage and marketing. Additionally, packaging conveys essential information about nutritional content, raw materials, manufacturer details, storage requirements and usage instructions [2]. Common packaging materials include paper, plastic, metal and glass, with plastic being the most widely used due to its durability and cost-effectiveness. However, the widespread use of plastic has led to serious environmental concerns, particularly related to its degradation, harmful impacts and waste management challenges. One of the main causes of the deterioration of the ecosystem is plastic garbage. Every year, more than 2 billion tons of municipal solid waste are generated worldwide, with a 70% rise predicted by 2050. Globally, approximately 381 million tons of plastic are produced each year, with single-use plastics accounting for a significant share of plastic packaging [3]. An estimated 5 trillion pieces of plastic are currently contaminating oceans, only 9% of plastic waste is recycled effectively,

leaving the majority (around 91%) either in landfills or unmanaged environments. This mismanagement contributes to soil and water contamination, while the incineration of plastics releases toxic pollutants, exacerbating air quality issues [4]. Most of this increase is expected to occur, where waste management systems are frequently insufficient. This causes soil contamination, water and air pollution, and poses serious risks to human health. Furthermore, plastics exacerbate climate change concerns by accounting for about 20% of methane emissions linked to human activity. To address these concerns, it is necessary to reduce plastic usage, implement advanced recycling technologies, and adopt sustainable packaging alternatives. Edible and biodegradable packaging represents a promising innovation in sustainable packaging solutions, offering an alternative to single-use plastics. In this context, researchers and institutes are continually exploring environmentally friendly materials that provide unique benefits [5].

Edible packaging uses materials that are safe for consumption and are designed to be ingested together with the packaged food. These materials are obtained from natural sources such as starches, proteins and seaweeds [6]. Edible packaging reduces waste and eliminates the need for additional disposal methods. In contrast, biodegradable packaging refers to materials that decompose naturally over time and return to the environment without leaving any harmful residues [7]. Plant-based polymers, compostable plastics and other organic substances are the common biodegradable materials, that break down through natural processes by microbial and enzymatic action. Decomposition of these materials occurs into non-toxic byproducts [8]. A combination of edible and biodegradable properties of materials in packaging provides a dual benefit. Consumers can enjoy the convenience of consuming and disposing of the packaging without harming the environment [9]. The development and adoption of such sustainable packaging solutions contribute to achieve the fundamental goal of reducing the environmental impact of packaging waste and contributing to a more circular and eco-friendly economy.

The importance of this topic in the context of environmental sustainability is underscored by the growing global concern over plastic pollution, which has severe ecological, economic, and health impacts. The accumulation of single-use plastics in oceans, landfills, and natural habitats threatens marine life, disrupts ecosystems, and contributes to greenhouse gas emissions throughout their lifecycle. As awareness of these issues increases, there is an need to explore and adopt sustainable, eco-friendly packaging solutions that minimize environmental harm, conserve natural resources, and support circular economy practices. Developing biodegradable, recyclable, and renewable-material-based packaging alternatives has therefore become a crucial step toward reducing environmental footprints and ensuring long-term ecological balance. Article "The futuristic trend of edible and biodegradable packaging, its impact and need: A review" aims to explore the growing popularity and significance of edible and biodegradable packaging in terms of environmental sustainability. This review article will likely discuss the benefits of these sustainable packaging, their potential impact on reducing waste and pollution and the need for their widespread adoption. It also covers the manufacturing processes, challenges, opportunities and prospects associated with edible and biodegradable packaging.

2. Methodology

To write this review article a systematic literature review was conducted using academic databases such as Research gate, Web of Science, PubMed, Scopus and Google Scholar by using keywords ‘Sustainable packaging’, ‘Edible packaging’, ‘Biodegradable packaging’, ‘environmental impact of plastic’, ‘Sustainability’, ‘Pollution’, ‘Economic consideration for sustainable packaging’. The literature survey covered publications from the year 2007 to 2024, ensuring the inclusion of research conducted over the past decade, along with the most recent advancements and developments in this field. Sources of evidence included research and review articles, short communications, peer-reviewed conference proceedings, book chapters, websites, and case studies of startups and

industries engaged in edible and biodegradable packaging. The following figure is showing the strategy used for searching the keywords.

Please place figure 1 here

3. Background and Development

Food packaging has evolved with various factors such as changing consumer preferences, technological advancements and growing environmental concerns. In the early phases of industrialization, packaging was primarily concerned with food preservation and prevention of spoilage. By the mid-20th century, the food industry witnessed a shift towards more convenient and cost-effective packaging solutions. Plastics became popular because they are versatile, lightweight, and affordable [10]. However, as concerns about plastic pollution and environmental sustainability evolved, the drawbacks of conventional packaging materials became evident. In response eco-friendly packaging solutions that are beneficial to the environment have gained more attention in recent years. These innovations aim to reduce environmental effect by utilizing biodegradable materials and reducing waste, in addition to preserving food quality [11]. The transition to biodegradable and edible packaging is a significant opportunity to reduce the environmental impact of solid waste management. These innovative solutions use agricultural and food processing waste [12]. As urban populations continue to expand, the implementation of such environmentally sustainable packaging practices is becoming essential, not only for reducing ecological footprints but also for enhancing public health and supporting long-term environmental sustainability.

Adoption of sustainable alternatives to conventional plastic packaging accelerated by increasing awareness of environmental issues, changing consumer attitudes toward sustainability and regulatory pressures. Biodegradable packaging materials are designed to break down naturally, reducing the environmental impact compared to non-biodegradable alternatives. Biodegradable packaging is mainly prepared from plant-

based materials, biopolymers, agricultural waste, mushroom-based substances and paper products [13]. Edible packaging takes sustainability a step further by allowing consumers to consume the packaging along with the food. This innovative approach aims to eliminate waste entirely. The surface phenomena known as edible packaging offers the stability and aeration that a variety of food products need. The way that edible packaging works is by using biomaterials to provide a coating or film around a food product. Edible packaging materials often include seaweed-based films, starch-based coatings, protein and lipid-based coatings and other food-grade ingredients [14]. The development of edible and biodegradable packaging is rooted in a historical progression of packaging trends. The emergence of these sustainable alternatives is fueled by environmental concerns, regulatory changes, shifting consumer preferences and advancements in technology. As the demand for eco-friendly options continues to grow, the packaging industry is likely to witness further innovations in sustainable packaging solutions. There are several widely developed forms and categories of edible and biodegradable packaging, as illustrated in Figure 2 below,

Please place Figure 2 here

4. Materials Used in Edible and Biodegradable Packaging

Packaging applications have seen a substantial transformation due to recent advancements in material science, with a special emphasis on edible and biodegradable packaging solutions. By leveraging natural resources and innovative processing techniques, these materials offer a viable solution to the pressing issue of plastic waste in the food industry [15]. Incorporation of bioactive components, antioxidants and antimicrobial agents enhances the quality of sustainable packaging [16]. Edible and biodegradable packaging materials are divided into different classes based on its sources, origin and characteristics as mentioned in (Table 1).

Please keep Table 1 here

These materials come under the category of biopolymers, polysaccharides, hydrocolloids, polypeptides, lipids and bio composites. Edible packaging materials are derived from natural sources such as starch, cellulose, chitosan, gelatin, chitin, alginate, chitosan, carrageenan, pectin, casein, whey, zein and soy proteins [17]. Polysaccharides are biopolymers derived from different sources, including plants, animals, microorganisms, seaweeds, fruits, agricultural waste, and by-products of food processing industries. These polysaccharides are processed into various forms such as cling films, coatings, and tableware that function as effective barriers against moisture, oxygen, and light. This barrier functionality is critical in extending the shelf life of food products by protecting them from environmental factors that accelerate degradation [18]. These biopolymeric materials exhibit excellent membrane and mechanical properties. They are inherently biodegradable, non-toxic, and possess antimicrobial activity. Additionally, they demonstrate favourable optical properties, making them suitable for food packaging applications where transparency and appearance are important. Among polysaccharide-based materials, cellulose derivatives play a significant role in edible packaging. Common cellulose-based derivatives include carboxymethylcellulose (CMC), hydroxypropyl cellulose (HPC), methylcellulose (MC), and hydroxypropyl methylcellulose (HPMC). These derivatives are widely utilized due to their film-forming ability, mechanical strength, and compatibility with food products [19]. Coatings on fruits and vegetables are frequently performed using lipid-based polymers, which typically include waxes and surfactants. These coatings form a semi-permeable layer that reduces moisture loss and gas exchange, thereby maintaining freshness and delaying ripening or spoilage. Furthermore, peptide-based polymers, primarily derived from protein sources such as collagen and gelatin, are employed in food packaging systems to enhance the shelf life of products. These protein-based polymers contribute to barrier properties and offer additional functionalities, including biodegradability and potential antimicrobial effects.

Biodegradable packaging material is composed of renewable raw materials and biodegradable additives. These materials enhance biodegradation under natural conditions, microbial and enzyme activity in water, soil and biomass [20]. Various polyesters are used in the formulation of biodegradable packaging that exhibit hydrophobic, antimicrobial and mechanical properties. Polymers create a barrier against light, moisture, gases and toxins to protect the food commodity [15]. Natural polyesters used in food packaging are: polyhydroxyalkanoates (PHAs) such as poly-3-hydroxybutyrate (PHB), polyhydroxy valerate (PHV) and polyhydroxyalkanoate (PHH); Renewables, such as a Polylactic acid (PLA); and purely Synthetics: Polybutylene succinate (PBS) and polycaprolactone (PCL). Materials like PLA and PHA are examples of bioplastics that offer biodegradable alternatives to traditional plastics [20]. PLA is particularly popular due to its versatility and transparency, making it suitable for various food packaging applications. Further, starch derivatives, cellulose esters, cellulose acetate, nitrocellulose and celluloid are available biodegradable polymers for packaging. The products of poly-anhydride and polyvinyl alcohol have been developed in recent times to develop novel biodegradable materials for the packaging industry [22].

Additives and gums, including plasticizers, antioxidants, antimicrobial agents, fillers, colorants, and flavoring compounds, are integral components in the formulation of edible and biodegradable packaging materials [24]. These substances significantly contribute to improving the functional properties of such packaging by enhancing mechanical flexibility, extending shelf life, providing microbial protection, improving sensory attributes and even biodegradation [25]. Plasticizers increases the flexibility and reduces brittleness of biopolymer films, thereby improving their durability and usability. Antioxidants help in preventing oxidative degradation of the packaging matrix, which is especially vital for preserving the quality of oxygen-sensitive packaged foods. Gums are naturally occurring biopolymers that are used for film formation, thickening, stability, emulsification and barrier properties [24, 25].

Substances such as glycerol are added to the films to improve flexibility and reduce brittleness, making them more suitable for packaging purposes. Incorporating essential oils, plant extracts and antimicrobial agents into edible film formulations improves their resistance to oxidation and microbial growth. Integration of natural gums and various additives in edible and biodegradable packaging not only addresses sustainability issues, but also enhances food preservation and safety [6]. An overview of these additives along with their specific properties in the development of edible and biodegradable packaging material, is presented in Table 2.

Please keep Table 2 here

5. Manufacturing Processes

The demand for sustainable alternatives to traditional food packaging has significantly increased in recent years due to growing environmental concerns and consumer awareness. This has driven the development of edible and biodegradable food packaging technologies, which vary according to raw materials used, the intended end-use and required quality attributes such as strength, barrier properties and biodegradability. Key manufacturing processes include extrusion, injection moulding, spraying, casting, lamination, coating, pulp moulding and compression moulding. Extrusion is widely used to produce continuous biodegradable films and sheets, while injection moulding creates rigid containers from biopolymers. Spraying and coating techniques apply a thin edible film that improves shelf life and reduce plastic usage. Pulp moulding and compression moulding are employed to produce sturdy, compostable trays and containers from cellulose-based materials. Table 3 summarises these methods along with their applications and materials compatibility, while Figure 3 illustrates the manufacturing processes involved in sustainable packaging development.

Please keep Table 3 and Figure 3 here

Extrusion: The extrusion process involves forcing raw material through a die to create continuous shapes like films or sheets. Extrusion takes place

in three stages feeding, mixing and shaping. Recent advancements have optimized extrusion process, raw material and parameters such as screw speed, temperature, moisture content, pressure and die size for production of flexible films that can be used as food packaging [10]. The extrusion process for developing edible and biodegradable packaging primarily involves two main techniques: blown film extrusion and cast film extrusion. In blown film extrusion, the polymer material is melted and extruded through a circular die, forming a thin tubular film. This film is then inflated by blowing air into it, expanding the tube to the desired thickness and width, which results in thin films suitable for packaging applications. The process is widely employed in packaging due to its ability to produce films with good mechanical properties and scalability. Cast film extrusion involves extruding the molten polymer material through a flat die onto a conveyor belt or roller. As the extrudate cools on the roller, it solidifies into a thin, uniform film with enhanced transparency and uniformity in thickness.

Injection moulding: This is a widely used manufacturing technique for the large-scale production of edible and biodegradable packaging materials. This process involves the injection of molten biopolymer into precision-designed moulds, followed by controlled filling, packing and cooling phases. Each stage is critically optimized by regulating temperature, pressure, and cooling rates to ensure the integrity, mechanical strength and dimensional accuracy of the final product. Advances in this technology have enabled the development of diverse range of sustainable items, including edible utensils, plates, bottles, and cutlery, which serve as eco-friendly alternatives to conventional plastic packaging and single-use consumer products. The use of biodegradable polymers such as polylactic acid (PLA), starch blends and protein-based materials enhances the environmental compatibility and functional performance of these products. Injection moulding offers reproducibility, scalability, and cost-effectiveness, making it a pivotal technology in the transition towards sustainable packaging solutions [28].

Spraying and coating: Edible or biodegradable materials are used for spraying and coating on the surface of commodities to provide barrier properties, ensure safety and improve packaging functionality [29]. In spraying technology for edible coatings, various methods such as dipping, fluidized bed coating, and panning are employed to uniformly apply functional coatings onto the surface of food products. These coatings serve to impart antifungal, antibacterial and antioxidant properties, thereby enhancing the shelf life and safety of the packaged food. To ensure consistent coating quality and fine particle distribution, advanced spray nozzle techniques are used [30]. With an emphasis on hygiene and precision, innovative approaches such as liquid electrostatic spraying have been developed to improve coating efficiency. This technology leverages electrostatic forces, wherein charged droplets of the coating solution are attracted to the grounded surfaces of food commodities. This mechanism significantly reduces coating waste and promotes uniform deposition, ultimately improving the overall effectiveness and sustainability of the coating process in edible and biodegradable packaging applications.

Casting: The casting method is one of the most widely adopted techniques for the fabrication of edible and biodegradable packaging films. In this process, biopolymers such as polysaccharides, proteins, and lipids, along with suitable plasticizers, are dissolved in an appropriate solvent system to prepare a homogeneous casting solution. The resulting solution is uniformly spread over a flat surface using a casting applicator, followed by controlled drying to facilitate solvent evaporation. After drying, the formed film is carefully peeled off, yielding a flexible and continuous packaging material [31].

Pulp moulding: Agricultural residues containing lignocellulosic fibers are processed and converted into pulp through suitable chemical and mechanical treatments. The prepared pulp is then molded into desired items using pulp moulding technology, followed by controlled drying to achieve structural stability. This sustainable technology is primarily applied in the production of moulded packaging materials including

containers, utensils, tableware and trays. Such fiber-based biodegradable products present a promising alternative to conventional petroleum-derived polymers, particularly styrofoam, thereby contributing to the development of eco-friendly packaging solutions [32].

Compression Moulding: Compression moulding represents one of the earliest and most established methods employed in the fabrication of edible and biodegradable packaging materials. This technique involves the application of high temperature and pressure to process natural polymers and cellulose-based raw materials. This method is considered highly energy-efficient and enables the rapid production of the final product with relatively simple operational requirements. In this process, the raw material is placed into a preheated mould, where compression under controlled pressure facilitates the formation of desired shapes and surface textures. Owing to its effectiveness, compression moulding has been widely utilized in the manufacture of sustainable, single use tableware items such as plates, bowls, spoons, containers, trays and cups [33].

3D Printing: 3D printing technology for edible and biodegradable packaging is an innovative approach in which materials suitable for human consumption or rapid environmental degradation are deposited in a layer-by-layer fashion to construct three-dimensional structures with customized geometries. This additive manufacturing method enables the fabrication of tailored packaging solutions, particularly for the confectionery, bakery, and extrusion sectors, addressing demands for personalization, sustainability, and functional performance. This technology in food packaging utilizes specially formulated edible or biodegradable materials, often derived from renewable resources or agricultural byproducts, to create complex and customizable shapes layer by layer through computer-controlled processes. These processes include extrusion-based, binder jetting, and inkjet techniques, allowing manufacturers to produce designs that would be difficult or impossible to achieve using conventional methods [34].

Mycelium Packaging: Mycelium packaging is an emerging innovation in sustainable packaging technology, derived from the root structures of mushrooms. This biodegradable and lightweight material is produced by cultivating fungal mycelium on agricultural waste substrates. It presents an eco-friendly alternative to conventional packaging materials such as polystyrene (styrofoam) and plastic, offering a renewable and compostable solution that reduces environmental impact [36].

6. Impact on food quality and safety

Edible and biodegradable packaging is an emerging trend in food industry due to its potential benefits on quality, safety of food products and environmental sustainability. Coating enhances shelf life of fresh commodities by providing barrier to moisture, oxygen, respiration and microorganisms that helps in prevention of spoilage [37]. Application of films on the surface of food products helps to maintain nutritional quality by minimizing the exposure of radiations, oxygen, temperature and light that degrades the sensitive micronutrients. The materials utilized in the manufacturing of this edible and biodegradable packaging contribute to the enhancement of organoleptic properties, thereby improving sensory attributes such as taste, aroma, texture, and appearance. Antioxidants, coloring and flavoring agents used in edible and biodegradable packaging help to retain texture and flavor of food products [38]. Application of antimicrobial agents for this packaging provides protection against foodborne pathogens. These packaging materials are developed from the natural sources, so there is no any health risk compared to traditional plastic packaging.

Understanding the interactions between food products and edible, biodegradable packaging materials is crucial for developing effective packaging solutions that maintain food quality, ensure safety, and align with sustainability objectives. Primary mechanisms of interaction include migration, permeation and absorption [39]. Migration describes the movement of materials from packaging into food. Type of food, material's nature and environmental parameters like time and temperature can affect

migration in edible and biodegradable packaging. For example, due to the less stable structures of these packaging compared to traditional plastics, they may allow more significant migration and lead to undesirable flavors and contamination. The transfer of gases or vapors through the packaging material is known as permeation [40]. Compared to traditional packaging materials, edible films have been reported to exhibit varying oxygen and moisture permeability, depending on their composition and processing conditions, which impact the food's freshness and shelf life. There is chance to absorb food products flavor, taste, aroma and moisture by packaging [41]. Edible and biodegradable packaging materials are designed not only to preserve food quality but also to enhance desirable flavor profiles while minimizing undesirable off-flavors. The nature of the polymers and raw materials employed plays a critical role in mediating the interactions between the packaging matrix and the food product. Consequently, selection of high-barrier materials is essential to effectively prevent negative sensory and quality alterations, thereby maintaining the overall integrity and shelf-life of the packaged food.

Edible and biodegradable packaging materials are generally subject to stringent safety regulations, ensuring they meet health standards for food contact substances. This compliance helps assure consumers about the safety of the packaging. Edible and biodegradable packaging is produced using natural ingredients and additives that are approved by the Codex Alimentarius Commission, the United States Food and Drug Administration, the European Food Safety Authority, and other national food safety regulatory agencies [10]. Every nation is strictly following the regulations regarding single-use plastic alternatives and environmental sustainability. To ensure compliance with food safety regulations, edible and biodegradable packaging materials must pose no health risks to consumers. These materials should be certified by recognized food safety authorities and classified as Generally Recognized As Safe (GRAS). Furthermore, if the raw materials contain any allergens with the potential to induce allergic reactions, such information must be clearly and accurately disclosed through appropriate labelling [42]. Packaging

materials are subject to strict safety regulations in many jurisdictions that evaluate how they interact with food items. Assessing the possible migration levels of materials from the packaging into the food is part of this. It is essential to adhere to Good Manufacturing Practices (GMP) during the development of edible and biodegradable packaging materials. Furthermore, any claims regarding the environmental benefits and biodegradability of such packaging must be substantiated through validated testing methodologies recognized and approved by relevant regulatory authorities.

7. Environmental impact

Environmental footprint of sustainable packaging is lower than that of plastic packaging. Conventional plastic packaging, primarily derived from non-renewable petroleum-based resources, persists in the environment for centuries due to its resistance to decomposition. This persistence contributes significantly to pollution, the emission of greenhouse gases, and poses detrimental effects to wildlife and marine ecosystems, thereby exacerbating climate change [43]. In contrast, edible and biodegradable packaging represent sustainable alternatives that mitigate environmental impact. These eco-friendly packaging materials are synthesized from compostable substances, promoting biodegradability and reducing ecological harm. Materials used in these packaging are derived from renewable resources, break down by natural processes and reduce landfill waste and emissions of greenhouse gases. These sustainable packaging solutions reveal several environmental benefits compared to conventional packaging. Biodegradable packaging can take weeks to months to degrade into soil and water under specific ecological conditions. This type of packaging offers significant advantages for improving the quality and safety of food products while concurrently contributing to the reduction of food waste. A comprehensive life cycle assessment of biodegradable packaging encompasses the characterization of raw materials, manufacturing processes, usage patterns, end-of-life scenarios, and degradation pathways [44]. Compared to conventional plastic packaging,

the production of sustainable packaging requires less energy and results in lower greenhouse gas emissions. Importantly, biodegradable packaging fulfils the functional roles of traditional packaging materials while providing the additional environmental benefit of reduced ecological footprint through its capacity for natural decomposition. These packaging break down into natural substances through composting or the biodegradation process, contributing to soil health and reducing waste in landfills.

8. Consumer perceptions, market dynamics, and marketing Approaches in the Edible and Biodegradable Packaging Sector

Rising consumer awareness about environmental sustainability, coupled with the escalating demand for eco-friendly alternatives, has driven significant advancements in packaging technologies. In this context, edible and biodegradable packaging materials have emerged as innovative packaging solutions, which not only mitigate the environmental impact associated with plastic waste but also align with the principles of a circular economy. According to projections, the global edible packaging industry increases from approximately $711 million in 2023 to $1.56 billion by 2032 and is expected to grow at a compound annual growth rate (CAGR) of around 5.54%. At a CAGR of 7.63% from 2024, the eco-friendly food packaging market, that includes biodegradable options and packaging solutions, is projected to reach $505 billion by 2034 [45]. According to recent research, customers prioritize hygiene and safety of food when choosing packaging, particularly in the wake of the COVID-19. Customers are willingly ready to pay more for environmentally friendly packaging with the consideration of sustainability. The growth of edible and biodegradable packaging is propelled by a confluence of factors, including escalating environmental concerns, technological innovations, evolving consumer lifestyles, and supportive regulatory frameworks. The detrimental environmental impacts of plastic waste have heightened public awareness and driven demand for sustainable packaging alternatives. Concurrently, ongoing research and technological advancements have enhanced the functionality, versatility, and consumer

appeal of edible and biodegradable packaging, ensuring these alternatives meet quality and performance standards comparable to conventional materials. Moreover, government policies and sustainability initiatives play a pivotal role in incentivizing the packaging industry to adopt green packaging solutions. These regulatory efforts aim to mitigate packaging-related waste and reduce greenhouse gas emissions, thereby fostering a circular economy and contributing to global environmental sustainability [46]. For the effective promotion of edible and biodegradable packaging, this sector should consider strategies as explained in (Table 4).

Addressing these factors has the potential to improve consumer acceptance and promote a reduction in the environmental footprint associated with traditional plastic packaging solutions.

Please place Table 4 here

9. Economic Considerations for the production and implementation of biodegradable and edible packaging

A thorough and systematic evaluation is essential to understand the economic consequences associated with the adoption of edible and biodegradable packaging, with specific attention to comprehensive cost analysis, financial incentives and the projection of long-term benefits [50]. Notably, the shift towards biodegradable and edible packaging solutions involves a range of costs that may differ significantly from those linked to conventional packaging materials. These costs encompass not only material procurement but also research and development, manufacturing process modifications, supply chain adjustments, and potential regulatory compliance expenses. Furthermore, factors such as scalability challenges, shelf-life stability, consumer acceptance, and environmental impact assessments contribute to the overall economic considerations. Comprehensive cost-benefit analyses are essential to evaluate the long-term financial and ecological implications of adopting sustainable packaging alternatives compared to traditional options. Due to limited supply chains, processes for manufacturing, and production capabilities, raw materials used in sustainable packaging are often more costly to manufacture than conventional plastics. Manufacturing processes for

sustainable packaging require new technologies or adaptations of current units, resulting in initial capital investments [51]. The growing demand for sustainable packaging is expected to encourage economies of scale, which will gradually decrease associated production costs. Businesses face a variety of economic incentives when considering shifting to sustainable packaging. Governments support the financial incentives, such as tax breaks or subsidies, to industries that invest in sustainable packaging innovations. This promotes innovation and the adoption of environmentally friendly approaches. Extended Producer Responsibility (EPR) schemes hold producers liable for the whole lifecycle of their products, encouraging them to develop more sustainable packaging alternatives. Increased demand from consumers for sustainable products encourages businesses to use eco-friendly packaging as a competitive advantage, which could contribute to increased sales.

As production scales increase, organizations may achieve cost savings through reduced waste management requirements and lower material prices. Implementing sustainable techniques has the potential to enhance operational efficiency. Industries that adopt such sustainable practices can strengthen their brand image and foster consumer loyalty, thereby positioning themselves favorably in a market that is increasingly influenced by environmental concerns. These developments lead to increasing market share and profitability in the future. As global regulations on plastic packaging waste become increasingly rigorous, early adopters of sustainable packaging may avoid potential fines and compliance costs associated with conventional plastic packaging methods. Overall, businesses that integrate sustainability principles are likely to strengthen their market presence and attract environmentally aware customers, potentially leading to future collaborations with other sustainability-oriented enterprises [50].

There is numerous case studies are available for edible and biodegradable packaging such as

1. **Evoware (Indonesia): Seaweed-Based Edible Packaging**

Evoware, an Indonesian firm, has created packaging that is both edible and biodegradable, utilising seaweed as its primary material. Evoware uses indigenous seaweed as its primary raw material, sourced locally from seaweed farmers, thereby supporting local livelihoods. The packaging produced by Evoware is suitable for dry and semi-wet food products, such as sandwich wraps and seasoning sachets, and extends to non-food items including straws, sanitary napkins, soaps, and toothpicks. These packaging products are free from animal derivatives, gelatin, and preservatives, making them Halal-certified and appropriate for vegetarians and vegans, which aligns with the dietary requirements of Indonesia's predominantly Muslim population [52].

2. **Qudrat (India): Edible-biodegradable Packaging**

   Qudrat, an Indian enterprise, manufactures entirely plant-based, consumable, and biodegradable packaging derived from rice husk and other natural components. The concept aims to deliver environmentally sustainable options for food packaging. Their offerings comprise edible utensils, cups and plates [53].

3. **Agricorn-Civita (Hungary): Maize-Based Packaging**

   Agricorn-Civita, a Hungarian enterprise, engages in the development and production of biodegradable edible tableware derived from corn biomass, including cups and plates. By utilizing corn, a renewable agricultural resource, the company significantly reduces reliance on conventional petroleum-based plastics, which are associated with environmental pollution and non-biodegradability. The adoption of corn-based edible tableware not only contributes to waste minimization and reduction of plastic pollution but also promotes the valorization of agricultural by-products, enhancing resource efficiency. Furthermore, this bioplastic alternative supports Hungary’s national objectives related to carbon footprint reduction and sustainable material innovation, positioning Agricorn-Civita at the intersection of agro-industrial development and eco-friendly consumer goods manufacturing [54].

10. Challenges and Opportunities in edible and biodegradable packaging sector

Edible and biodegradable packaging sector is gaining popularity as a sustainable alternative to conventional plastic packaging materials. It faces significant challenges, but it also provides several opportunities for innovation and collaboration. Key challenges and opportunities in edible and biodegradable packaging are explained in (Table 5).

Please place Table 5 here

11. Role of Policy and Regulation

Government policies and regulations play a pivotal role in advancing the adoption of edible and biodegradable packaging, thereby contributing significantly to environmental sustainability and pollution control. Comprehensive government initiatives, including the enforcement of bans on single-use plastics, alignment with United Nations Sustainable Development Goals (SDGs), and the provision of subsidies to promote entrepreneurship, are instrumental in fostering the development and market penetration of sustainable packaging alternatives [56]. These policies serve to create an enabling environment that facilitates innovation and supports eco-friendly practices within the packaging industry. The regulatory prohibition of single-use plastics has been a critical step toward reducing plastic waste accumulation and mitigating its detrimental environmental effects. This is often supplemented by incentive mechanisms such as grants, tax rebates, and subsidies aimed at stimulating research, development, and commercialization of biodegradable packaging products derived primarily from natural sources and waste biomass. Moreover, adherence to established international standards, including biodegradability certification processes, is essential to ensure consumer safety, environmental compliance, and to build market trust through transparent labelling practices [57].

In close synergy with these regulatory interventions, the United Nations SDGs, particularly Goal 12 on Responsible Consumption and Production,

provide a global framework encouraging the shift towards sustainable packaging solutions. The integration of these goals into national policies underscores the importance of sustainable packaging in achieving environmental targets such as climate action, ecosystem preservation, and reduction of plastic pollution [56]. Equally important to regulatory efforts is the development of robust waste management systems. Effective collection, processing, and recycling infrastructure are imperative to close the material loop and realize the “waste to wealth” potential of biodegradable materials. Investments in infrastructure, supported by policy frameworks that encourage public-private partnerships, are essential to enhance the efficacy of waste management systems and facilitate the circular economy model.

12. Future Prospects

The future of edible and biodegradable packaging looks bright as innovations continue to emerge in response to environmental challenges. With increasing market demand, supportive regulations and technological advancements, sustainable packaging could play a vital role in reshaping the food industry towards more sustainable practices. This shift encompasses predictions for material evolution, research directions and potential impacts on global sustainability. There is a significant trend towards using biodegradable materials derived from natural sources such as plant starches, sugarcane baggage, bamboo fiber, natural fibers, animal proteins, seaweed, coconut coir and agricultural waste. The future of edible and biodegradable packaging lies in the sustainable exploitation of various renewable resources such as plant parts, industrial by-products, and agricultural residues, which having the potential to valorize for large-scale production. Utilizing these raw materials not only reduces dependency on petroleum-based plastics but also contributes significantly to waste management and circular bioeconomy development. To ensure quality, safety, and functional performance, the integration of advanced technologies is imperative. Techniques such as micro- and nano-fluidization, digitalization of production systems, and incorporation

of intelligent sensors are expected to enhance barrier properties, mechanical strength, and real-time monitoring of packaging integrity. Furthermore, the adoption of smart traceability tools-including Radio Frequency Identification (RFID) tags, Near-Field Communication (NFC), and blockchain-based platforms-can simultaneously improve the transparency, authenticity, and efficiency of supply chains while facilitating consumer trust in food safety. Another prospective research pathway is the synergistic application of edible and biodegradable packaging with non-thermal food preservation technologies. Limited studies have explored the compatibility of such packaging materials with emerging techniques like ultraviolet (UV) irradiation, cold plasma, pulsed electric fields, and pulsed light treatments. Investigating these hurdle technology combinations could offer dual benefits of extending the shelf-life and microbial safety of food products by improving the physicochemical stability and biodegradability of packaging materials.

Future research should focus on enhancing the mechanical properties of biodegradable materials to meet industry standards for durability while remaining environmentally friendly. Product acceptability is mainly based on the consumer demand and acceptance, so research is being conducted on consumer behaviour towards these innovative solutions, focusing on sensory attributes, safety, convenience and cytotoxic studies. Developing clear regulations regarding the use of biodegradable and edible packaging is needed which includes, defining standards for its degradation, safety, hygiene and environmental sustainability to facilitate broader acceptance in the market. Migration effects of edible and biodegradable packaging with food products need to be studied. Promoting the use of renewable resources and reducing reliance on fossil fuels, biodegradable packaging supports the principles of a circular economy. This transformation can lead to more sustainable production practices across variety of enterprises. This could result in more efficient recycling systems based on composting rather than landfilling. More comprehensive study is required to achieve a viable plastic-free packaging sector with the alternative solution of edible and biodegradable packaging in the coming future with the

achievement of sustainable development goals (SDG) such as responsible consumption and production (SDG-12), climate action (SDG-13), life below water (SDG-14), life on land (SDG-15), as shown in Figure 4.

Please place Figure 4 here

13. Conclusion

Edible and biodegradable food packaging trend represents a promising and significant response to the pressing environmental challenges posed by traditional plastic packaging materials. Demand for eco-friendly alternatives has raised as consumers become increasingly aware of sustainability issues. This review has highlighted the advantages and importance of edible and biodegradable packaging materials and described how they can improve sustainability measures. Edible and biodegradable packaging materials have emerged as sustainable alternative to conventional plastic-based packaging as these innovative materials are safely consumed, composted, or utilized as animal feed, thereby substantially minimizing the ecological footprint and mitigating the waste management challenges associated with plastic packaging. By minimizing reliance on non-renewable resources and promoting circular economy practices, these packaging solutions not only contribute to ecological sustainability but also align closely with evolving consumer preferences for safer, eco-friendly, and health-conscious food systems. The impact of using these materials goes beyond waste reduction; it promotes a circular economy in which resources are reused rather than discarded. Regulatory frameworks are progressively encouraging biodegradable solutions, exhibiting a cultural movement toward more sustainable initiative. As research and manufacturing processes continue to advance, the commercial viability of edible and biodegradable packaging material is expected to improve, potentially enhancing their accessibility to both manufacturers and consumers. However, realizing this potential will depend on sustained investment in research and development to overcome existing technical and economic challenges. Collaboration among stakeholders in the food sector including producers, retailers and policy

makers remains essential to address issues related to cost-effectiveness and material performance. Additionally, consumer education plays a vital role in fostering acceptance and promoting the adoption of these emerging sustainable packaging solutions. By identifying sustainable packaging options, we collectively contribute to a healthier planet while meeting the evolving demands of environmentally conscious consumers. The adoption of edible and biodegradable packaging therefore represents necessary direction for research and development towards achieving sustainability in food production, consumption, safety and environmental protection.

Abbreviations

CMC	Carboxymethylcellulose
HPC	Hydroxypropyl cellulose
MC	Methylcellulose
HPMC	Hydroxypropyl methylcellulose
PHAs	Polyhydroxyalkanoates
PHB	Poly-3-hydroxybutyrate
PHV	Polyhydroxy valerate
PHH	Polyhydroxyalkanoate
PLA	Polylactic acid
PBS	Polybutylene succinate
PCL	Polycaprolactone
CAGR	Compound annual growth rate
RFID	Radio frequency identification

NFC	Near field communication
UV	Ultraviolet
SDG	Sustainable development goals

Conflict of Interest Declaration

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

Ethical Approval and Consent to Participate

Ethical approval: Not applicable.
Consent to participate: Not applicable.

Consent to Publish

Not applicable

Funding Information

The funding is supported by University of Debrecen Program for scientific publication.

Acknowledgements

The authors express gratitude to partner institutions and the University of Debrecen. The first author also extends sincere thanks to SARTHI-Pune (CSMNRF-22) for doctoral support.

References

1. Saklani P, Siddhnath Das SK, Singh SM. A review of edible packaging for foods. International Journal of Current Microbiology and Applied Sciences. 2019;8(7): 2885–2895. https://doi.org/10.20546/ijcmas.2019.807.359

2. Das P, Borah PP, Badwaik LS. Transformation of Chicken Feather Keratin and Pomelo Peel Pectin into Biodegradable Composite

Film. Journal of Polymers and the Environment. 2018; 26:2120–2129. https://doi.org/10.1007/s10924-017-1109-z

3. Jafarzadeh S, Jafari SM. Impact of metal nanoparticles on the mechanical, barrier, optical and thermal properties of biodegradable food packaging materials. Critical Reviews in Food Science and Nutrition. 2020; 61(16): 2640–2658. https://doi.org/10.1080/10408398.2020.1783200

4. Shaji George. Biodegradable Ecofriendly Sustainable Tableware and Packaging: A Comprehensive Review of Materials, Manufacturing, and Applications. 2023; 2(2):202-228. https://zenodo.org/records/8051038

5. Marisa C, Gaspar, Mara EM Braga. Edible films and coatings based on agrifood residues: a new trend in the food packaging research. Current Opinion in Food Science. 2023; 50: 101006. https://doi.org/10.1016/j.cofs.2023.101006

6. Abdul Khalil HPS, Banerjee A, Saurabh CK, Tye YY, Suriani AB, Mohamed A, Karim A A, Rizal S, Paridah MT. Biodegradable films for fruits and vegetables packaging application: preparation and properties. Food Engineering Reviews. 2018; 10(3):139–153, https://doi.org/10.1007/s12393-018-9180-3

7. Abhijith R, Ashok A, Rejeesh CR. Sustainable packaging applications from mycelium to substitute polystyrene: A review. Materials Today: Proceedings. 2018; 5(1): 2139–2145. https://doi.org/10.1016/j.matpr.2017.09.211

8. Tharanathan RN. Biodegradable films and composite coatings: past, present and future, Trends in Food Science and Technology. 2003; 14(3): 71-78. https://doi.org/10.1016/S0924-2244(02)00280-7

9. Savenkova L, Gercberga Z, Nikolaeva V, Dzene A, Bibers I, Kalnin M. Mechanical properties and biodegradation characteristics of

PHB-based films. Process Biochemistry. 2000; 35(6):573–579. https://doi.org/10.1016/S0032-9592(99)00107-7

10. Nair SS, Trafiałek J. Kolanowski W. Edible Packaging: A Technological Update for the Sustainable Future of the Food Industry. Applied Sciences. 2023; 13(14): 8234. https://doi.org/10.3390/app13148234

11. Verma MK, Shakya S, Kumar P. Trends in packaging material for food products: historical background, current scenario, and future prospects. Journal of Food Science and Technology. 2021; 58: 4069–4082. https://doi.org/10.1007/s13197-021-04964-2

12. Sharma C, Dhiman R, Rokana N, Panwar H. Nanotechnology: An Untapped Resource for Food Packaging. Frontiers in microbiology. 2017; *8*: 1735. https://doi.org/10.3389/fmicb.2017.01735

13. Jin T, Zhang H. Biodegradable polylactic acid polymer with nisin for use in antimicrobial food packaging. Journal of food science. 2008; *73*(3), M127–M134. https://doi.org/10.1111/j.1750-3841.2008.00681.x

14. Rhim JW, Ng PK. Natural biopolymer-based nanocomposite films for packaging applications. Critical reviews in food science and nutrition. 2007; 47(4): 411–433. https://doi.org/10.1080/10408390600846366

15. Kumari S, Debbarma R, Nasrin N, Khan T, Taj S, Bhuyan T. Recent advances in packaging materials for food products. Food Bioengineering. 2024; *3*(2): 236-249. https://doi.org/10.1002/fbe2.12096

16. Hejazian SA, Ghorbani-HasanSaraei A, Ahmadi M. The effect of chia seed mucilage shell coating in combination with turmeric essential oil on egg shelf life and quality properties. Food Measure. 2023; 17: 4175–4190. https://doi.org/10.1007/s11694-023-01923-7

17. Asgher M, Qamar SA, Bilal M, Iqbal HMN. Bio-based active food packaging materials: Sustainable alternative to conventional petrochemical-based packaging materials. Food Research International. 2020; *137*:109625. https://doi.org/10.1016/j.foodres.2020.109625

18. Varghese SA, Pulikkalparambil H, Promhuad K, Srisa A, Laorenza Y, Jarupan L, Nampitch T, Chonhenchob V, Harnkarnsujarit N. Renovation of Agro-Waste for Sustainable Food Packaging: A Review. Polymers. 2023; *15*: 648. https://doi.org/10.3390/polym15030648

19. Macias-Almazan A, Lois-Correa JA, Dominguez-Crespo MA, Lopez-Oyama AB, Torres-Huerta AM, Brachetti-Sibaja SB, Rodriguez-Salazar AE. Influence of operating conditions on proton conductivity of nanocellulose films using two agroindustrial wastes: Sugarcane bagasse and pinewood sawdust. Carbohydrate Polymer. 2020; 238, 116171. https://doi org/10.1016/j. carbpol.2020.116171

20. Weligama Thuppahige VT, Karim MA. A comprehensive review on the properties and functionalities of biodegradable and semibiodegradable food packaging materials. Comprehensive Reviews in Food Science and Food Safety. 2021; *21*(2):689-718. https://doi.org/10.1111/1541-4337.12873

21. Wang N, Yu J, Ma X. Preparation and characterization of thermoplastic starch/PLA blends by one-step reactive extrusion. Polymer International. 2007; 56(11): 1440–1447. https://doi.org/10.1002/ pi.2302

22. Priya B, Gupta VK, Pathania D, Singha AS. Synthesis, characterization, and antibacterial activity of biodegradable starch/PVA composite films reinforced with cellulosic fibre. Carbohydrate Polymers. 2014; *109*:171–179. https://doi.org/10.1016/j.carbpol.2014.03.044

23. Latos-Brozio M, Masek A. The application of natural food colorants as indicator substances in intelligent biodegradable packaging materials. Food and Chemical Toxicology. 2020; *135*, 110975. https://doi.org/10.1016/j.fct.2019.110975

24. Fu J, Alee M, Yang M, Liu H, Li Y, Li Z, Yu L. Synergizing Multi-Plasticizers for a Starch-Based Edible Film. Foods. 2022; 11 (20): 3254. https://doi.org/10.3390/foods11203254

25. Sharma G, Sharma S, Kumar A, Al-Muhtaseb AH, Naushad M, Ghfar AA, Mola GT, Stadler FJ. Guar gum and its composites as potential materials for diverse applications: A review. Carbohydrate Polymers. 2018; *199*, 534-545. https://doi.org/10.1016/j.carbpol.2018.07.053

26. Sanches-Silva A, Costa D, Albuquerque TG, Buonocore GG, Ramos F, Castilho MC, Machado AV, Costa HS. Trends in the use of natural antioxidants in active food packaging: a review. Food additives & contaminants. Part A, Chemistry, analysis, control, exposure & risk assessment. 2014; *31*(3): 374–395. https://doi.org/10.1080/19440049.2013.879215

27. Nehra A, Biswas D, Siracusa V, Roy S. Natural Gum-Based Functional Bioactive Films and Coatings: A Review. International journal of molecular sciences. 2022; 24(1): 485. https://doi.org/10.3390/ijms24010485

28. Lisitsyn A, Semenova A, Nasonova V, Polishchuk E, Revutskaya N, Kozyrev I, Kotenkova E. Approaches in Animal Proteins and Natural Polysaccharides Application for Food Packaging: Edible Film Production and Quality Estimation. Polymers. 2021; *13*(10), 1592. https://doi.org/10.3390/polym13101592

29. Krishna Priya N, Thirunavookarasu N, Chidanand DV. Recent advances in edible coating of food products and its legislations: A review. Journal of Agriculture and Food Research. 2023; *12*, 100623. https://doi.org/10.1016/j.jafr.2023.100623

30. Gupta D, Lall A, Kumar S, Patil TD, Gaikwad KK. Plant-based edible films and coatings for food-packaging applications: Recent advances, applications, and trends. Sustainable Food Technology. 2024; 2: 1428-1455 https://doi.org/10.1039/D4FB00110A

31. Prakoso FAH, Indiarto R, Utama GL. Edible film casting techniques and materials and their utilization for meat-based product packaging. Polymers. 2023; 15(13): 2800. https://doi.org/10.3390/polym15132800

32. Semple KE, Zhou C, Rojas OJ, Nkeuwa WN, Dai C. Moulded pulp fibers for disposable food packaging: A state-of-the-art review. Food Packaging and Shelf Life. 2022; 33, 100908. https://doi.org/10.1016/j.fpsl.2022.100908

33. Anirudh MK, Lal AMN, Harikrishnan MP, Jose J, Thasim J, Warrier AS, Venkatesh R, Vaddevolu UBP, Kothakota A. Sustainable seedling pots: Development and characterisation of banana waste and natural fibre-reinforced composites for horticultural applications. International Journal of Biological Macromolecules. 2024; *270*: 132070. https://doi.org/10.1016/j.ijbiomac.2024.132070

34. Rodríguez-Parada L, de la Rosa S, Sánchez Salado J, Desmet P, Pardo-Vicente MA. Edible innovations: Testing the WOW impact of 3D printed chocolate packaging. Food Quality and Preference. 2024; 123: 105337. https://doi.org/10.1016/j.foodqual.2024.105337

35. Andanje MN, Mwangi JW, Mose BR, Carrara S. Biocompatible and Biodegradable 3D Printing from Bioplastics: A Review. Polymers. 2023; *15*: 2355. https://doi.org/10.3390/polym15102355

36. Sivaprasad S, Byju SK, Prajith C, Shaju J, Rejeesh CR. Development of a novel mycelium bio-composite material to substitute for polystyrene in packaging applications. Materials Today: Proceedings. 2021; 47(15): 5038-5044. https://doi.org/10.1016/j.matpr.2021.04.622

37. Panou A, Karabagias IK. Biodegradable Packaging Materials for Foods Preservation: Sources, Advantages, Limitations, and Future Perspectives. Coatings. 2023: 13: 1176. https://doi.org/10.3390/coatings13071176

38. Alamri MS, Qasem AAA, Mohamed AA, Hussain S, Ibraheem MA, Shamlan G, Alqah HA, Qasha AS. Food packaging's materials: A food safety perspective. Saudi Journal of Biological Sciences. 2021; 28(8), 4490-4499. https://doi.org/10.1016/j.sjbs.2021.04.047

39. Pereira de Abreu DA, Cruz JM, Paseiro Losada P. Active and intelligent packaging for the food industry. Food Reviews International, 2012; 28(2), 146–187. https://doi.org/10.1080/87559129.2011.595022

40. Wani AK, Anjli A, Tripathi I, Mir TUG. Interaction of food and packaging. In S. P. Bangar & M. Trif (Eds.), Developments in food quality and safety: Intelligent packaging. 2024; (pp. 289–318). Academic Press. https://doi.org/10.1016/B978-0-443-15388-4.00011-0

41. Vimala Bharathi SK, Moses JA, Anandharamakrishnan C. Interaction Phenomena Between Packaging and Product. In: Ahmed, S. (eds) Bio-based Materials for Food Packaging. Springer, Singapore. 2018; https://doi.org/10.1007/978-981-13-1909-9_2

42. Olivas GI, Barbosa-Cánovas G. Edible Films and Coatings for Fruits and Vegetables. In: Huber, K., Embuscado, M. (eds) Edible Films and Coatings for Food Applications. Springer, New York, NY. 2009; https://doi.org/10.1007/978-0-387-92824-1_7

43. Ncube LK, Ude AU, Ogunmuyiwa EN, Zulkifli R, Beas IN. Environmental Impact of Food Packaging Materials: A Review of Contemporary Development from Conventional Plastics to Polylactic Acid Based Materials. Materials. 2020; 13(21): 4994. https://doi.org/10.3390/ma13214994

44. Anand K, Arce AM, Bishop G, Styles D, Fitzpatrick C. A tasty solution to packaging waste? Life cycle assessment of edible coffee cups. Resources, Conservation and Recycling. 2024; 201, 107320. https://doi.org/10.1016/j.resconrec.2023.107320

45. Precedence Research. Eco-friendly food packaging market size, share, report. 2024; *2023–2032*. https://www.precedenceresearch.com/eco-friendly-food-packaging-market

46. Horská E, Šedík P, Mušinská K, Savitskaya T, Grinshpan D, Kačániová M. Acceptability of edible food packaging in Slovakia: A case study on young generation. Frontiers in Sustainable Food Systems. 2021; *5*. https://doi.org/10.3389/fsufs.2021.720700

47. Bojanowska A, Sulimierska A. Consumer Awareness of Biodegradability of Food Products Packaging. Sustainability. 2023; *15*: 13980. https://doi.org/10.3390/su151813980

48. Taylor S, Colonna A, Jung J, Gutierrez J, Zhao Y. Consumer perception and acceptance of edible packaging for various food products. Journal of food science. 2024; 89(4), 2423–2437. https://doi.org/10.1111/1750-3841.16992

49. Zhang X, Wen H, Shao X. Understanding consumers' acceptance of edible food packaging: The role of consumer innovativeness. Journal of Retailing and Consumer Services. 2024; 80, 103903. https://doi.org/10.1016/j.jretconser.2024.103903

50. Tassinari G, Bassani A, Spigno G, Soregaroli C, Drabik D. Do biodegradable food packaging films from agro-food waste pay off? A cost-benefit analysis in the context of Europe. Science of the Total Environment. 2023; *856*, 159101. https://doi.org/10.1016/j.scitotenv.2022.159101

51. Boz Z, Korhonen V, Koelsch Sand C. Consumer Considerations for the Implementation of Sustainable Packaging: A

Review. Sustainability. 2020; 12, 2192. https://doi.org/10.3390/su12062192

52. Rethink Plastic. Home. Retrieved December 12, 2024, from https://rethink-plastic.com/home/

53. Qudrat. Home. Retrieved December 12, 2024, from https://qudrat.co.in/

54. Agricorn. Home. Retrieved December 12, 2024, from http://www.agricorn.hu/

55. Fekete E, Német B, Miskolczi N. Sustainable biodegradable coatings for food packaging: Challenges and opportunities. Green Chemistry. 2023; 25(16), 4745-4762. https://doi.org/10.1039/D3GC02647G

56. Jahangiri F, Mohanty AK, Misra M. Sustainable biodegradable coatings for food packaging: Challenges and opportunities. Green Chemistry. 2024; 26(9), 4934–4974. https://doi.org/10.1039/D3GC02647G

57. Oliveira ACS, Ribeiro MN, Ugucioni JC, Rocha RA, Borges SV. Consumer perception of biodegradable packaging for food. Polímeros: Ciência e Tecnologia. 2023; 33(4), e20230045. https://doi.org/10.1590/0104-1428.20230068

List of figures

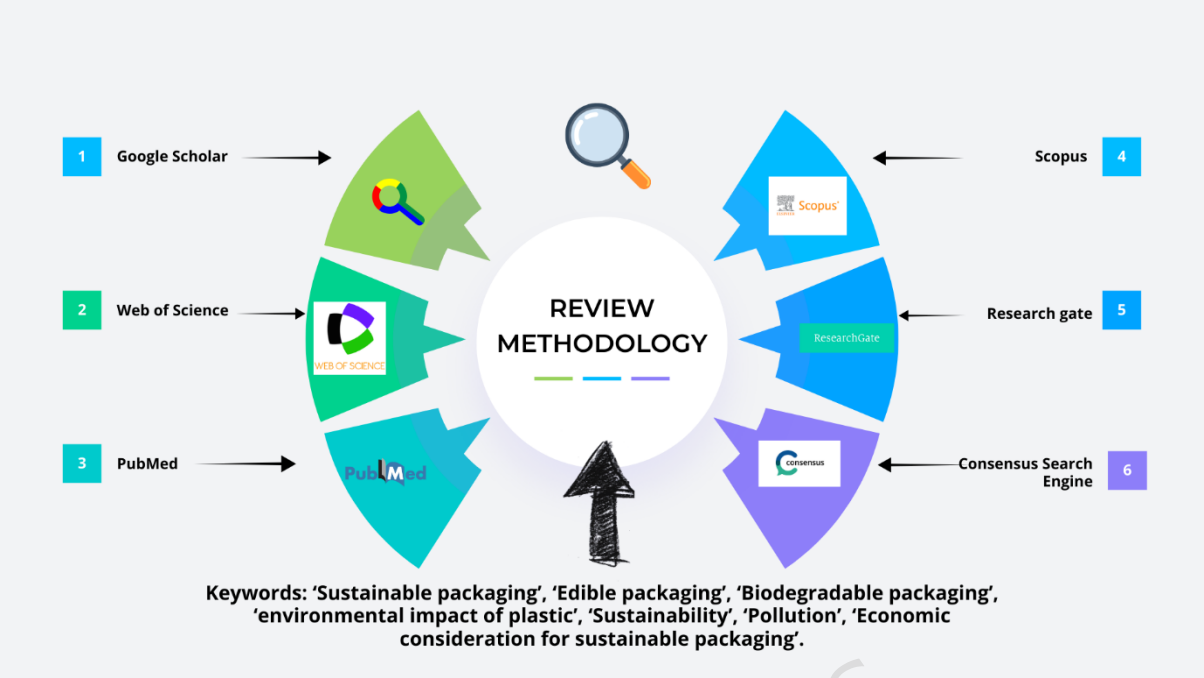

Figure 1.Showing the strategies used for the review

Figure 2. Showing categories of edible and biodegradable packaging

(Source: Author, For coating: https://www.sageoilllc.com/blog/fruit-wax-coating-supplier/)

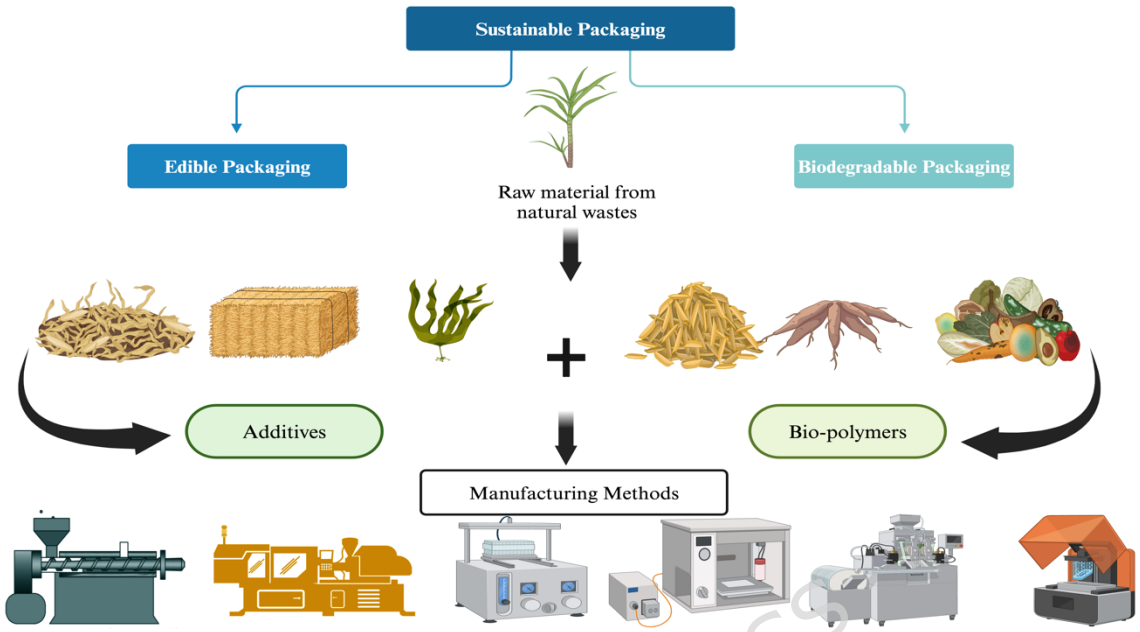

Figure 3. Manufacturing processes for edible and biodegradable packaging (Source: Author, Created using Bio-render)

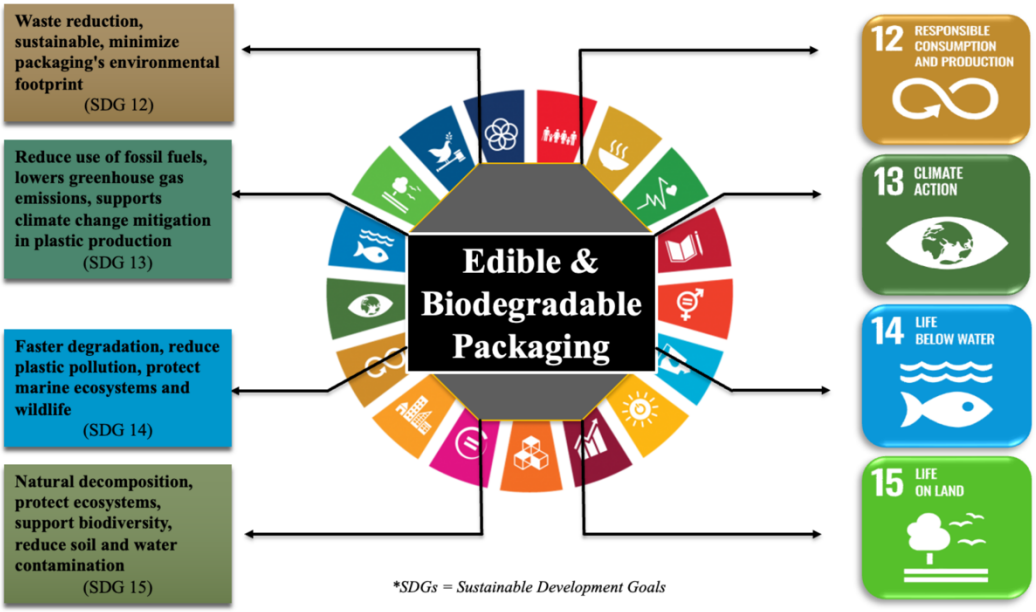

Figure 4. Showing sustainable solution output using SDS'S (Source: Author, Created using Bio-render and https://sdgs.un.org/goals)

Table 1: Materials used in the formulation of edible and biodegradable packaging

Class	Sub class	Sources	Applications	References
Polysaccharides	Starch	Corn, Rice, Potato, Tapioca	Edible coatings, films, food packaging	[18, 19, 20,21,22,23]
	Cellulose	Agriculture waste, wood pulp	Paper making, films, coating	
	Pectin	Fruit peel, pomace	Edible spraying, coating, films	
	Agar	Seaweed	Films, coatings	
	Carrageenan	Seaweed	Coating, film	
	Chitosan	Shellfish, microbial biomass	Antimicrobial coatings, films, packaging	
	Gelatin	Bones, shells, animal skin, fish	Coatings, films, spraying	
Protein	Casein, whey	Cheese, Paneer processing	Films, coating	
	Soy	Soybeans	Films, coating, packaging	
	Zein	Corn	Films, coatings	
Lipids	Waxes	Honeycombs, plant leaves, carnauba, rice bran	Water resistant edible coatings, packaging, spraying	
	Surfactants	Soybean, plant oil, oil seeds	Moisture barrier films, packaging containers	

	Shellac	Insect secretions	Coatings	
Biopolymers	PHA	Microbial fermentation	Films, containers, packaging materials	
	PLA	Sugarcane, corn	Packaging materials, cutlery,	
Fibers	Plant based fibres	Banana, pineapple, sugarcane, bamboo, coconut, cactus, rice straw, husk, bran, leaves	Biodegradable containers, tableware, plates	
Composites	Fibre composites	Rice, corn, wheat	Food containers, cutlery	
Natural polymers	Lignin	Agriculture waste	Biodegradable films and packaging	

Table 2: Additives, classification and its properties for development of edible and biodegradable packaging material

Additives	Examples	Properties	References
Plasticizers	Glycerol, Sorbitol	Improve flexibility, reduce brittleness	[24]
Antioxidants	Tocopherols, Ascorbic Acid, phenolic compounds	Prevent oxidative degradation, maintain quality of product	[26]
Antimicrobial agents	Essential oils, bioactive components, Nisin	Inhibit microbial growth, increase shelf life, safety of food products	[24]
Gums	Xanthan gum, guar gum, agar, Carrageenan, pectin, gum arabic	Enhances flexibility, reduces brittleness, provides viscosity, stability, and elasticity to films, Improve film-forming properties and mechanical properties, enhance barrier properties, uniformity in film texture	[25,27]
Fillers	Nanoclays, Calcium Carbonate, starch	Improve barrier properties, enhance mechanical strength	[6]
Colorants and Flavors	Extracts, pigments	Enhance appearance, sensory appeal	[23]

Table 3: Methods used for manufacturing of edible and biodegradable packaging and its applications

Methods	Raw material	Applications	References
Extrusion	PLA, PHA, polysaccharides	Packaging films, containers	[10]
Injection moulding	PLA, PHA, natural binders, starch blends	Bottles, cutlery items	[28]
Spraying and coating	Plant based polysaccharides, protein, lipids and binders	Coating of fresh fruits, vegetables, eggs, fish, meat products and food wraps	[30,31]
Casting	Natural materials including starch, proteins, lipids, gum and solvents	Cling films for coating of fresh fruits and vegetables, wrapping of food products	[31]
Pulp moulding	Cellulose fibres, rice straw, wheat bran, sugarcane bagasse, additives	Food packaging, containers, trays, tableware	[32]
Compression moulding	Agriculture fibre based materials, binders	Tableware including plates, bowls, cup and containers	[10,33]
3D Printing	Flours, starch, fibre, PLA, natural binders, colorants, flavour	Customized containers, holders, tray, boxes, bowl	[34, 35]

Mycelium Packaging	Agriculture waste, fungi roots	Food containers, cushioning moulds	[7,36]

Table 4: Marketing strategies for of edible and biodegradable packaging

Strategies	**Solutions**	**References**
Education and Awareness	Information to consumers regarding benefits of edible and biodegradable packaging by marketing campaigns, and acts that highlight environmental impacts, health problems and wastage associated with plastic packaging	[47]
Sensory marketing	Selection of packaging is based on the sensory attributes and overall appearance. This is carried out by conducting sensory evaluations of edible and biodegradable packaging to showcase quality and acceptance of product	[48]
Cost competitiveness	Ensure that the cost of edible and biodegradable packaging is competitive with traditional plastic packaging. This will help to enhance consumer acceptance and encourage wider adoption	[49]

Labelling compliance	Labelling helps to communicate between the consumer and sustainability aspects of the packaging to make informed choices	[48]

Table 5: Challenges and opportunities in edible and biodegradable packaging sector

Challenges	Opportunities	References
Mechanical properties: Compare to conventional plastics edible and biodegradable packaging materials exhibit lower mechanical strength and stability, under different environmental conditions like temperature and humidity. This property also impacts on the ability to protect food commodities effectively. This packaging is less durable in nature so adequate protection during transportation and storage remains a critical concern.	**Research and Development**: There is significant potential for innovation in developing new biodegradable materials derived from under-utilized food ingredients, food processing byproducts and agricultural waste. This leads to more sustainable production practices while reducing food and agriculture waste.	[55]
Production costs: The cost of production for edible and biodegradable packaging is generally higher than that of traditional packaging due to the sourcing of	**Collaboration**: Partnerships between food manufacturers, packaging industries, researchers and policymakers can drive advancements in edible and biodegradable packaging	[56]

raw materials, innovation in technologies and less established manufacturing processes.	technologies. Collaborative efforts can help share knowledge, reduce costs and promote best practices across the industry.	
Consumer acceptance: There are barriers related to consumer perception of edible packaging, including concerns about taste, texture and hygiene. Visual aspects of biodegradable packaging and its different forms significantly influence consumer preferences as the consumers prefer lighter and quality product with its safety.	**Market demand**: Growing consumer awareness regarding environmental issues presents an opportunity for businesses to adopt sustainable practices, enhancing brand reputation and customer loyalty. Industries investing in sustainable packaging may attract consumers who are eco-conscious and willing to pay for sustainable products.	[57]
Regulatory issues: The industry faces challenges regarding safety regulations and standards for biodegradable materials. Ensuring compliance with these regulations can complicate the development and marketing of new packaging solutions. Edible and	**Lifestyle enhancement**: Edible and biodegradable packaging will help to improve community lifestyle with easy handling without their adverse effects on health and non-toxicity nature. This packaging innovation reduce the cost of recycling. Open	[56]

biodegradable packaging are directly or indirectly in the contact of food so the Food and Drug Administration (FDA) information and guidelines should be given by supplier.	the new avenue for agriculture, pharmaceutical and polymer and allied sector. Waste utilization helps to reduce pollution.	