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Biodegradable Films: Sustainable Solutions for Food Packaging Applications

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Abstract

The increasing environmental implications of conventional plastic packaging has led to a raising interest in biodegradable packaging materials as sustainable alternatives. Biodegradable materials, derived from sustainable resources such as plant-based biopolymers and natural fibers, offer significant environmental benefits, including reduced reliance on fossil fuels and decreased pollution. Various techniques can be employed for forming biodegradable packaging films, including extrusion, solvent casting, compression molding and electrospinning. To address the limitations of biodegradable materials compared to traditional plastics, modification techniques such as esterification, etherification, and grafting can be employed. Innovative advancements like active and intelligent packaging technologies can enhance the functionality and consumer engagement. This review explores the key properties, advancements, applications and challenges associated with biodegradable packaging materials, focusing on their effectiveness and sustainability in the food packaging industry.

Keywords: Biodegradable packaging, Sustainable materials, Food packaging, Active packaging, Film-forming techniques.

1. Introduction

The packaging serves a multitude of crucial purposes in the modern food industry and in our daily lives [1]. It acts as a barrier of protection safeguarding food products from physical damage, contamination and spoilage thereby preserving their quality, freshness and safety. Packaging also contributes substantially to extending the perishable commodities shelf life, reducing food waste and enabling efficient distribution and storage throughout the supply chain [2]. Additionally, packaging provides essential information to consumers, such as nutritional content, ingredients, allergen warnings, and expiration dates, empowering them to make informed purchasing decisions and ensure food safety. It facilitates convenience and portability, making it easier for consumers to transport, handle, and consume food products, whether at home, on-the-go, or in various settings [3].

Plastic-based food packaging has been widely used for its versatility, durability, and cost-effectiveness [4]. These plastic packaging materials also have significant drawbacks and environmental consequences [5]. One of the main disadvantages of plastic-based packaging of food is its persistence in the environment. Plastics accumulate in landfills, oceans, and ecosystems because they take hundreds to thousands of years to break down [6]. Because of ingestion and entanglement, this accumulation seriously endangers species and disrupts ecosystems and biodiversity. Moreover, millions of tons of plastic waste get generated annually as a consequence of plastic packaging, contributing to the global plastic pollution catastrophe [7]. Improper disposal and inadequate recycling infrastructure exacerbate this problem, leading to littering, pollution, and microplastic contamination in the environment, waterways, and food chain. The problem is so serious that even plastics of micro scale have been detected in human blood [8], human testis and semen [9]. Furthermore, a large portion of the manufacturing of plastic packaging utilizes fossil fuels, which increases greenhouse gas emissions and adds to the impact of climate change. The extraction, manufacturing, and disposal of

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plastics consume significant energy and resources, further exacerbating environmental degradation and resource depletion [4]. These food packaging materials made of plastic frequently include dangerous chemicals like phthalates and bisphenol A (BPA), which may penetrate into food and drink and pose health hazards, particularly when exposed to them for an extended period of time [10]. The growing public awareness and demand for forced the development of biodegradable packaging materials.

A viable substitute for conventional plastic packaging is provided by biodegradable food packaging materials, which solve the environmental issues related to plastic waste and pollution [11]. As these materials are made to naturally decompose over time into non-toxic components, packaging waste has a lesser effect on the environment [12, 13]. One of the key advantages of biodegradable food packaging materials is their ability to mitigate plastic pollution. Unlike traditional plastics, which persist in the environment for hundreds of years, biodegradable materials undergo microbial degradation, returning valuable nutrients to the soil and water [14]. This helps prevent littering, reduces landfill accumulation, and minimizes harm to wildlife and ecosystems. Moreover, biodegradable food packaging materials are often derived from renewable resources, such as plant-based biopolymers, agricultural residues, or natural fibers [15, 16]. By utilizing renewable feedstocks, these materials reduce reliance on finite fossil fuels and contribute to a more sustainable and circular economy. In addition to their environmental benefits, biodegradable food packaging materials have some draw backs as their functionality and performance is inferior to traditional plastics. These materials need optimum modifications to make them suitable for their application [17]. Advancements in research and development have led to the emergence of innovative biodegradable packaging solutions, such as active and intelligent packaging technologies, which can enhance food quality, extend shelf life, and improve traceability and safety [18]. Biodegradable food packaging materials hold great promise as a sustainable alternative to plastic packaging, offering a pathway towards reducing plastic pollution, conserving resources, and promoting a more environmentally friendly and resilient food system. This review provides an overview of advancements in biodegradable food packaging.

2. Types of Biodegradable Materials

Several different types of materials have been utilized to develop biodegradable packaging materials some of these have been discussed below.

Biopolymers derived from renewable resources, such as plants or microorganisms. They include polylactic acid (PLA) [19], polyhydroxyalkanoates (PHA) [20], Polyhydroxybutyrate (PHB) [15], Carrageenan [21] and starch-based polymers [22]. These materials offer good barrier attributes and mechanical strength, making them suitable for a variety of food packaging applications. Natural fibers, such as cellulose [16], hemicellulose [23], and lignin [24] derived from plant sources and offer biodegradability and renewability. These materials can be used to reinforce biopolymer matrices or as standalone packaging materials. Different biodegradable materials can be combined to form composite materials to achieve specific properties and functionalities. Biodegradable polymers can be reinforced with natural fibers [16] or fillers [25] to enhance mechanical strength and barrier properties. Composite materials offer versatility and customization options, allowing for tailored solutions to meet specific packaging requirements. Proteins derived from plant or animal sources can be used to create biodegradable packaging materials with unique properties and functionalities. Proteins such as whey protein [26], gluten [27], or casein [28] can be processed into films, coatings, or edible packaging solutions. Protein-based biodegradable packaging materials offer advantages such as good barrier attributes, biocompatibility, and potential for edible applications. These biodegradable materials offer alternatives to traditional plastic packaging, providing sustainable options to reduce environmental impact and promote circularity in the food packaging industry.

3. Techniques to Develop Biodegradable Packaging

Various techniques have been employed to form biodegradable packaging materials. Some of them have been discussed below. Figure 1 shows various techniques to develop biodegradable films.

Solution Casting: On the lab scale solution casting approach has been employed predominantly [29]. In this method biopolymers to be used for film formation is dissolved in a solution along with the incorporation of other additives like plasticizers, crosslinkers, nanoparticles/fibrils and other bioactive compounds. After appropriate mixing these solutions are cast in petri dishes and vacuum dried to remove water. After drying the films are peeled and stored in desiccator till further processing [30]. The solution casting approach has its downside it cannot be used for large scale production of biopolymers. Solution casting method was utilized by Sutay et al. [31] to form plasticized hemicellulose films derived olive mill waste. Similarly Jaderi et al. [32] employed casting approach to form Malva sylvestris flower gum films.

Extrusion: For large scale production of biodegradable materials extrusion have been employed. In extrusion biopolymers and additives are mixed by application of high temperature, pressure and shear forces [33]. After blending the material is passed through a narrow die to get the desired shape. Extrusion has proved to be suitable option for large scale production of biodegradable material due to its continuous nature [34]. The extrusion technique was utilized by Faust et al. [35] to form pea protein isolate films using a twin screw extruder. Bahcegul et al. [36] utilized twin screw extruder to develop biodegradable polymeric material from xylan derived from corncobs.

Electrospinning: Electrospinning is an approach that can be employed at lab as well as at an industrial scale [37]. At first a solution of biopolymers and additives is created after that the solution is filled in a syringe. A high voltage is applied between tip and the collection plate of the syringe. A thin stream of the mixture emerges from the tip which is dried by the air. The dried material form fibers which are deposited on the collection plate. An elevated temperature can be utilized to further dry the fibers [38]. This method has a drawback that it cannot be utilized for formation of thin films [39]. Antimicrobial biodegradable films based on poly (butylene adipate-co-terephthalate) has been developed using electrospinning [40].

Compression molding: Compression molding method can be utilized at any scale to form biodegradable films [41]. It involves blending and molding biopolymers and additives. Either cold or hot compression can be applied to cure the films that is crosslinking of biopolymers [42]. de Matos Costa et al. [43] utilized compression molding to form films based on Polybutylene succinate and Polybutylene adipate-co-terephthalate.

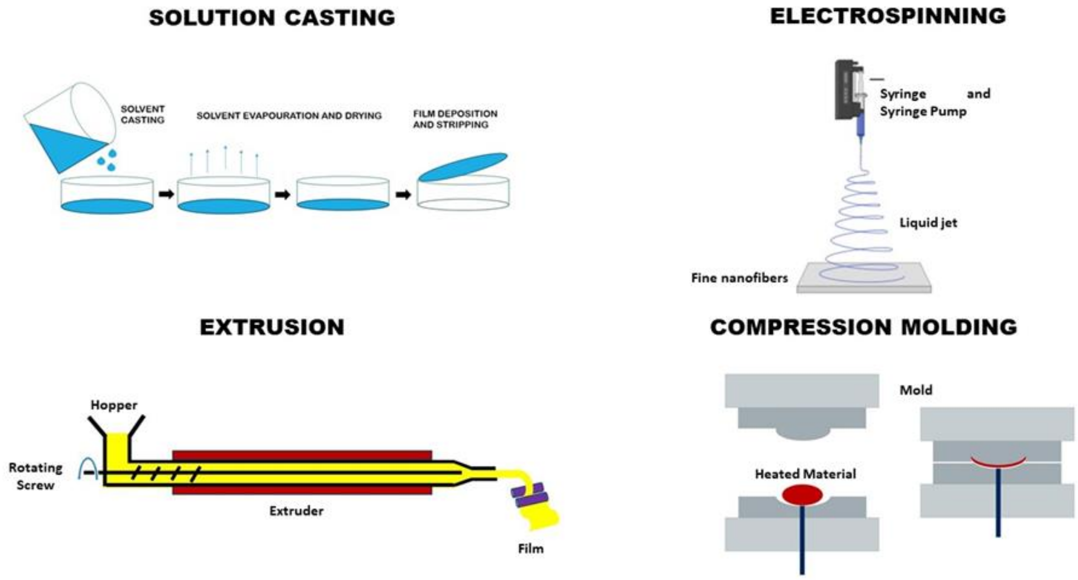
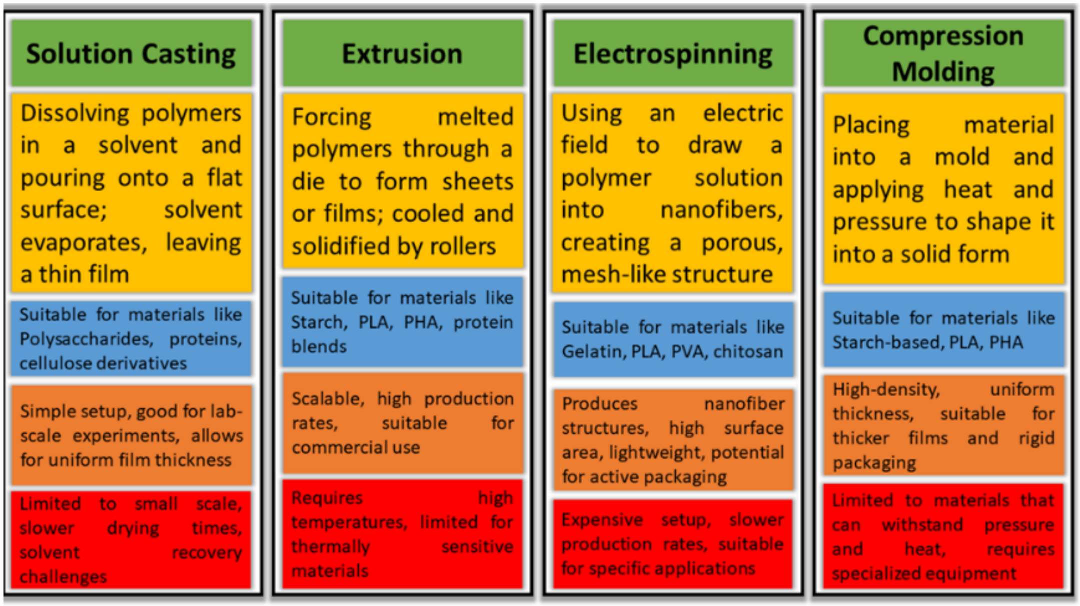


Figure 1. Various Techniques to Develop Biodegradable Films

The selection of a development method for packaging materials depends on the ingredients, desired attributes of the final product, and production scale. The casting method is versatile but suitable only for small-scale production. Other methods have their specific limitations like electrospinning requires electrically charged biopolymers, extrusion is unsuitable for biopolymers that degrade under compression methods, high temperatures, high pressures, or high shear rates are only appropriate for biopolymers that set when compressed or heated. Figure 2 provides a comparison of the film forming methods.



Solution Casting	Extrusion	Electrospinning	Compression Molding
Dissolving polymers in a solvent and pouring onto a flat surface; solvent evaporates, leaving a thin film	Forcing melted polymers through a die to form sheets or films; cooled and solidified by rollers	Using an electric field to draw a polymer solution into nanofibers, creating a porous, mesh-like structure	Placing material into a mold and applying heat and pressure to shape it into a solid form
Suitable for materials like Polysaccharides, proteins, cellulose derivatives	Suitable for materials like Starch, PLA, PHA, protein blends	Suitable for materials like Gelatin, PLA, PVA, chitosan	Suitable for materials like Starch-based, PLA, PHA
Simple setup, good for lab-scale experiments, allows for uniform film thickness	Scalable, high production rates, suitable for commercial use	Produces nanofiber structures, high surface area, lightweight, potential for active packaging	High-density, uniform thickness, suitable for thicker films and rigid packaging
Limited to small scale, slower drying times, solvent recovery challenges	Requires high temperatures, limited for thermally sensitive materials	Expensive setup, slower production rates, suitable for specific applications	Limited to materials that can withstand pressure and heat, requires specialized equipment

Figure 2. Comparison of the film forming methods

4. Properties and Characteristics

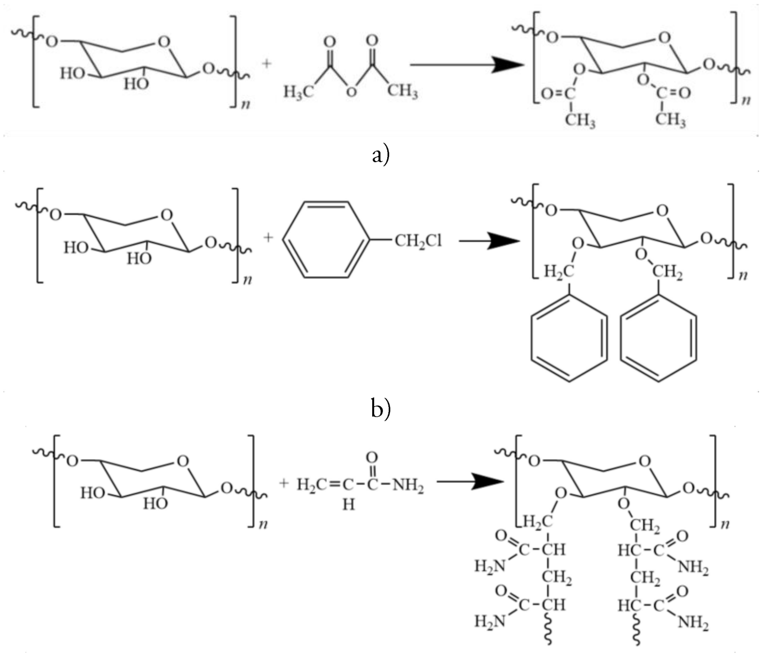
Biodegradable packaging materials exhibit several key properties essential for their effectiveness and sustainability in the food packaging industry. Firstly, their biodegradability enables them to naturally break down into harmless components when exposed to environmental conditions, reducing their environmental footprint and promoting circularity in the packaging lifecycle [44]. Additionally, these materials can be engineered to provide adequate barrier properties [45, 46] mechanical strength, thickness and opacity [32] ensuring the safety, quality, and freshness of packaged foods throughout their shelf life. The properties of biodegradable packaging materials play a pivotal role in balancing environmental considerations with functional requirements and regulatory compliance in the development of sustainable packaging solutions for the food industry however they are inferior to the attributes of plastic based packaging materials so there is a need to modify them.

5. Modifications of the Properties

Modification of the attributes of biodegradable packaging materials involves tailoring their characteristics to meet specific application requirements and enhance their performance in various packaging contexts. Several strategies can be employed to modify the properties of biodegradable packaging materials, including:

Additives and reinforcements: Incorporating additives such as plasticizers [47], fillers [25], or reinforcements [48] into biodegradable materials can improve their barrier attributes, mechanical strength, and thermal stability. For example, fillers such as nanocellulose [49] or montmorillonite nanoparticles [50] can be added to biopolymer matrices to enhance their tensile strength and gas barrier properties, making them suitable for flexible packaging applications. Plasticizers such as glycerol and sorbitol can be incorporated to improve the properties of biodegradable films [32]. In a similar manner reforcements such as egg shell can be employed to achieve desirable characteristics [51].

Blending and composite formation: Blending biodegradable polymers with other materials or creating composite structures allows for the combination of different properties to achieve desired functionalities [52-54]. For instance, El Miri et al. [55] developed bionanocomposite films based of cellulose nanocrystals filled with alginate. In a similar manner polyvinyl alcohol and citric acid composite films were produced by Wang et al. [56].


a)

b)

c)

Figure 3. Esterification (a), Etherification (b) and Grafting (c) of Hemicellulose

Chemical modifications: Esterification, etherification, and grafting are chemical modification approaches commonly utilized to enhance the attributes and functionality of polymers, including biodegradable packaging materials. Esterification can improve the compatibility, hydrophobicity, and thermal stability of polymers, thereby enhancing their barrier properties and mechanical strength [57]. Etherification of these materials can enhance the flexibility, solubility, and compatibility of polymers, making them more suitable for specific packaging applications [58]. Grafting process enhances the compatibility between biopolymers and additives or to introduce functional groups for targeted applications leading to improved mechanical strength, adhesion, or compatibility with other materials [59]. Figure 3 shows esterification, etherification and grafting of hemicellulose [17].

Crosslinking and polymerization: Crosslinking [60] or polymerization [61] reactions can be employed to modify the molecular structure of biodegradable polymers, leading to changes in their mechanical, thermal, and degradation properties. Figure 4 shows the crosslinking of hemicellulose films [17].

By tailoring the properties of biodegradable packaging materials to specific application requirements, it is possible to develop sustainable packaging solutions that meet the evolving needs of the food industry while promoting environmental stewardship and resource conservation

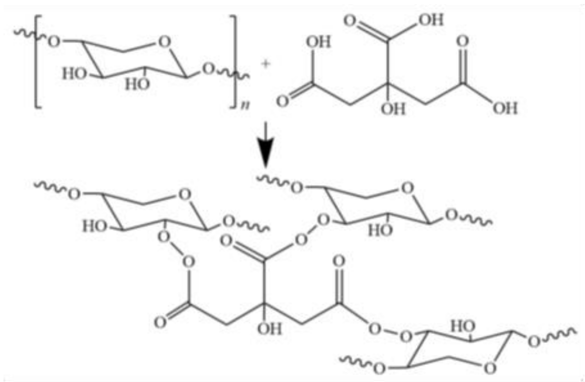


Figure 4. Crosslinking of Hemicellulose Films

6. Advencements

Advancements in biodegradable food packaging have led to the development of innovative solutions such as active and intelligent packaging, which offer enhanced functionality beyond traditional passive packaging materials [62]. Figure 5 Shows Active and Intelligent packaging systems for packaging.

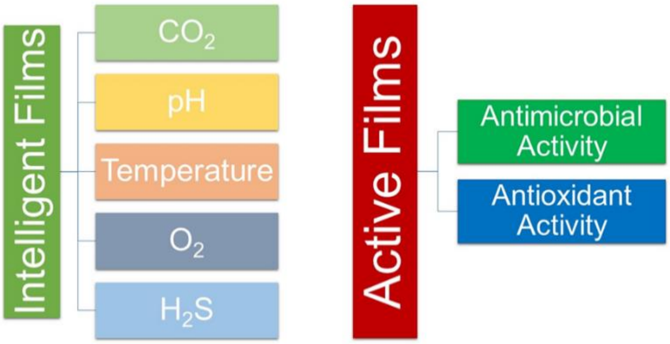


Figure 5. Intelligent and Active Food Packaging Systems

Active packaging systems are designed to interact with the packaged food or its environment to extend shelf life, maintain quality, and improve safety [63]. Active packaging systems typically incorporate active components, such as oxygen scavengers [64], antimicrobial agents [65], or ethylene scavengers [66], into the packaging material or the package itself. These components actively interact with the packaged food or its surroundings to inhibit microbial growth, control ripening, or reduce oxidative reactions, thereby extending the shelf life and preserving the quality of perishable foods. Biodegradable chitosan and gelatin films were formed by Xu et al. [67] these films were incorporated with hop extract which not only enhanced the antioxidant activity of these films but also proved effective against bacteria. Lian et al. [68] formed chitosan and pullulan active films by including thyme essential oil. A substantial decline in E. coli activity was noted by the incorporation of thyme essential oil. Citric acid was incorporated in PVA and starch based by Wu et al. [69] The activity of E. coli was sufficiently inhibited by the inclusion of citric acid. Table 1 provides a summary of effects of active materials on biopolymer based packaging

Table 1. A summary of effects of Active Materials on Biopolymer based Packaging

Biopolymer	Active Material	Effects	References
Chitosan	Pine needle extract	High antioxidant effect was noted.	[70]
Methylcellulose	Silver nanoparticles	Bacterial growth was inhibited	[71]
Poly(lactic acid)/ Poly(caprolactone)	thymol, carvacrol	Enhanced antioxidant activity was observed.	[72]
Gelatin	Rosmarinic acid	Bacterial growth was inhibited	[73]
Polylactic acid	thymol, kesum, curry	Bacterial growth was inhibited	[74]
Polyvinyl alcohol	Pomegranate peel extract	Bacterial growth was inhibited	[75]
Sodium lactate/whey protein isolate	E-Poly lysine	Bacterial growth was inhibited	[76]
Fish gelatin	Haskap Berry Extracat	radical scavenging activity was enhanced	[77]
Chitosan/Carboxymethyl Cellulose	ZnO nanoparticles	Bacterial and Fungal activity was sufficiently controlled.	[78]
Chitosan	Black plum peel extract	DPPH inhibition was enhanced and bacterial growth was controlled	[79]
Sodium alginate	ZnO nanoparticles	A decline in bacterial count was observed.	[80]
Hydroxypropyl methyl cellulose	*Thymus daenensis* EO	Bacterial growth was inhibited	[81]
Whey protein isolate	Lactoferrin, Lysozyme, and the Lactoperoxidase	Bacterial growth was inhibited	[82]

Sensors and indicators are incorporated into intelligent packaging to give real-time information about the state of the packaged goods [83]. These technologies represent significant advancements in the field of food packaging, offering benefits in terms of food preservation, quality assurance, and consumer convenience. Intelligent packaging incorporates sensors [84] and indicators [85] that give precise information regarding the state of the product in its packaging, including its Freshness, temperature, gas composition, moisture content. These technologies allow for monitoring and control of critical parameters throughout the supply chain, enabling timely interventions to maintain food safety and quality. Jamróz et al. [86] formed furcellaran and gelatin-based films with the incorporation of extract from pu-erh and green tea. Jung et al. [87] utilized 2-amino-2-methyl-1-propanol and chitosan as a carbon dioxide indicator to monitor quality of fermented foods. Pucci et al. [88] developed biodegradable PLA and PBS films with temperature indicator by incorporating 4,4′ -bis(2-benzoxazolyl) stilbene. Vu et al. [89] incorporated redox dyes in biopolymers to act as oxygen indicators. Table 2 provides a summary of effects of intelligent materials on biopolymer based packaging.

Table 2. A summary of effects of Intelligent Materials on Biopolymer based Packaging

Biopolymer	**Intelligent Material**	**Effect**	**References**
Chitosan/Polyvinyl Alcohol	Anthocyanin	Change of color provided spoilage indication.	[90]
Hydroxy propyl methylcellulose/ K-carrageenan	Anthocyanin	Change of color provided spoilage indication.	[91]
Cellulose acetate nanofibers	Alizarin	Change of color provided spoilage indication.	[92]
Glucomannan/Polyvinyl alcohol	Betacyanin	pH change was indicated by change of color.	[93]
Polylactide/Poly hydroxybutyrate	β-carotene, Chlorophyll, Curcumin, Lutein	Change in temperature changed the color.	[94]
Agar	*Arnebia euchroma* root	Change of color provided spoilage indication.	[95]
Bacterial cellulose nanofibers	Anthocyanin	Gas production changed the color.	[96]
Cellulose-Polyvinyl alcohol	Acidochromic dye	pH change was indicated by change of color.	[97]
Furcellaran, gelatin	Green tea extract	pH change was indicated by change of color.	[86]
Succinylated chitosan and hydroxypropyl chitosan	Bromocresol blue and methyl red	Color change indicated change of carbon dioxide concentration.	[98]
Artemisia sphaerocephala Krasch. Gum	Anthocyanins	NH_3 presence changed the color.	[99]
Chitosan and agarose	Anthocyanins	Change of color provided spoilage indication.	[100]
Low-acyl gellan gum	Silver Nanoparticles	Color changed with the presence of H_2S.	[101]
Alginate	Molybdenum trioxide nanoparticles	Color changed with the presence of H_2S.	[102]

7. Applications of biodegradable Packaging

Innovations in food packaging have reached new heights with the advent of various cutting-edge films and coating materials, each with specific applications to enhance food preservation and consumer satisfaction. Anti-sprouting films, utilizing polymeric carriers infused with natural anti-sprouting agents like essential oils, are used to extend the shelf life of potatoes and other sprout-prone produce, providing a sustainable alternative to conventional fogging techniques [103]. High-performance UV-blocking films protect packaged foods such as dairy and beverages from photooxidation, ensuring prolonged shelf life and quality retention [104]. Nano-engineered films, incorporating nanomaterials, are applied to improve the mechanical strength and barrier properties of packaging for fragile items like snacks and baked goods [105]. Two-dimensional materials like nano-cellulose and metal nanoparticles are used to enhance the thermal and mechanical properties of packaging for perishable items like fruits and vegetables [106]. Multi-shaded films find application in the confectionery industry, making products like candies more visually appealing [107]. Taste and odor-masking films are particularly useful for packaging nutritious yet strong-smelling foods such as garlic, onions, and durian, improving consumer acceptance [108]. Oxygen [109] and water [110] resistant films are essential for packaging fresh produce, meats, and fermented foods, maintaining optimal freshness and quality [111]. Transparent films are ideal for packaging products like meat and seafood, allowing consumers to inspect the product visually [112]. The emergence of 2D and 3D printed films enables precise customization for high-end products and specialty foods [113]. Super-hydrophobic/hydrophilic films are used in applications requiring anti-fouling and self-cleaning properties, such as ready-to-eat meals [114]. Smart pH-sensitive films provide real-time monitoring of food spoilage, crucial for perishable goods like seafood and dairy products [115]. Multilayer films, integrating barrier, active, and control layers, are versatile for packaging a wide range of food items, from dry goods to liquids [116]. Active films enriched with antimicrobials and antioxidants are applied to packaging for fresh produce and meats to enhance food safety [117]. Plasticized [118] and cross-linked [119] are used in applications requiring flexibility and durability, such as packaging for processed foods and snacks. These advancements collectively herald a new era of innovation in food packaging technology, promising enhanced sustainability, functionality, and consumer satisfaction across the globe.

8. Future Directions and Challenges

The implementation of biodegradable packaging involves addressing key challenges and advancing the development, adoption and scalability of sustainable packaging solutions. While biodegradable packaging holds great promise for reducing environmental impact and promoting circularity in the packaging industry several challenges need to be overcome to realize its full potential. These challenges include technological limitations, regulatory barriers, market demand and end-of-life management considerations.

There is a need to heavily fund research and development in order to overcome the drawbacks of biodegradable packaging materials. Mechanical strength and barrier qualities can be enhanced by ongoing developments in biopolymer technology, such as the production of novel polymers like polylactic acid (PLA) and polyhydroxyalkanoates (PHA). Furthermore, the overall performance of biodegradable films can be enhanced by the development of nanocomposites using nanotechnology. Research collaborations between academic institutions, business partners, and government organizations could accelerate the development of economical and efficient sustainable packaging solutions. It is essential to have strong legal frameworks and uniform guidelines for biodegradable packaging materials. International organizations and governments need to collaborate to establish regulations that guarantee environmental sustainability, quality, and safety. A circular economy for plastics, for instance, is the goal of programs like the European Union's Plastics Strategy, which can be extended to include biodegradable materials. Involving stakeholders in the regulatory process can help create certification programs that increase customer confidence and make choosing biodegradable packaging solutions easier. Targeted consumer education initiatives are necessary to raise awareness of the environmental advantages of biodegradable packaging alternatives and drive market demand for them. Acceptance can be enhanced by interacting with customers on social media and showcasing successful biodegradable packaging case studies in marketing campaigns. To guarantee that consumers have access to reasonably priced and highly effective biodegradable products, manufacturers, merchants, and waste management firms must work together. End-of-life management considerations are essential for ensuring the effective disposal, recycling, and composting of biodegradable packaging materials. While biodegradation offers a promising solution to reduce packaging waste, infrastructure and logistical challenges exist in implementing widespread composting or recycling facilities. Investment in infrastructure development, improving collection and sorting processes, and promoting circular economy models to close the loop on biodegradable packaging materials is necessary to and maximize resource recovery.

9. Conclusion

Biodegradable packaging materials represent a promising solution to the environmental challenges posed by traditional plastic packaging. With advancements in biopolymers, natural fibers, and protein-based materials, these sustainable alternatives offer potential benefits such as reduced pollution, renewable sourcing, and improved food safety and quality. However, the successful implementation of biodegradable packaging requires overcoming several challenges, including technological limitations, regulatory barriers, market acceptance, and effective end-of-life management. Future efforts must focus on continued innovation, harmonized regulations, consumer education, and infrastructure development to fully realize the potential of biodegradable packaging. By addressing these challenges, the packaging industry can move towards a more sustainable and circular economy, minimizing environmental impact while meeting the functional needs of food packaging.

References

[1] Trajkovska Petkoska, A., Daniloski, D., D'Cunha, N.M., Naumovski, N., Broach, A.T. (2021). Edible packaging: Sustainable solutions and novel trends in food packaging. Food Res Int; 140:109981.

[2] Jin, K., Tang, Y., Liu, J., Wang, J., Ye, C. (2021). Nanofibrillated cellulose as coating agent for food packaging paper. Int J Biol Macromol; 168:331-8.

[3] Otto, S., Strenger, M., Maier-Nöth, A., Schmid, M. (2021). Food Packaging and Sustainability – Consumer Perception vs. Correlated Scientific Facts: A Review. J Cleaner Prod; 298:126733.

[4] Molina-Besch, K., Wikström, F., Williams, H. (2018). The environmental impact of packaging in food supply chains—does life cycle assessment of food provide the full picture? Int J Life Cycle Assess; 24:37-50.

[5] Rodrigues, M.O., Abrantes, N., Goncalves, F.J.M., Nogueira, H., Marques, J.C., Goncalves, A.M.M. (2019). Impacts of plastic products used in daily life on the environment and human health: What is known? Environ Toxicol Pharmacol; 72:103239.

[6] Yin, W., Qiu, C., Ji, H., Li, X., Sang, S., McClements, D.J., et al. (2023). Recent advances in biomolecule-based films and coatings for active and smart food packaging applications. Food Biosci; 52.

[7] Asgher, M., Qamar, S.A., Bilal, M., Iqbal, H.M.N. (2020). Bio-based active food packaging materials: Sustainable alternative to conventional petrochemical-based packaging materials. Food Res Int; 137:109625.

[8] Leslie, H.A., van Velzen, M.J.M., Brandsma, S.H., Vethaak, A.D., Garcia-Vallejo, J.J., Lamoree, M.H. (2022). Discovery and quantification of plastic particle pollution in human blood. Environ Int; 163:107199.

[9] Zhao, Q., Zhu, L., Weng, J., Jin, Z., Cao, Y., Jiang, H., et al. (2023). Detection and characterization of microplastics in the human testis and semen. Sci Total Environ; 877:162713.

[10] Groh, K.J., Backhaus, T., Carney-Almroth, B., Geueke, B., Inostroza, P.A., Lennquist, A., et al. (2019). Overview of known plastic packaging-associated chemicals and their hazards. Sci Total Environ; 651:3253-68.

[11] Nilsen-Nygaard, J., Fernandez, E.N., Radusin, T., Rotabakk, B.T., Sarfraz, J., Sharmin, N., et al. (2021). Current status of biobased and biodegradable food packaging materials: Impact on food quality and effect of innovative processing technologies. Compr Rev Food Sci Food Saf; 20:1333-80.

[12] Yao, L., Fan, L., Duan, Z. (2020). Effects of different packaging systems and storage temperatures on the physical and chemical quality of dried mango slices. LWT; 121:108981.

[13] Jafarzadeh, S., Jafari, S.M., Salehabadi, A., Nafchi, A.M., Uthaya Kumar, U.S., Khalil, H.P.S.A. (2020). Biodegradable green packaging with antimicrobial functions based on the bioactive compounds from tropical plants and their by-products. Trends Food Sci Technol; 100:262-77.

[14] Hadidi, M., Jafarzadeh, S., Forough, M., Garavand, F., Alizadeh, S., Salehabadi, A., et al. (2022). Plant protein-based food packaging films; recent advances in fabrication, characterization, and applications. Trends Food Sci Technol; 120:154-73.

[15] Popa, M.S., Frone, A.N., Panaitescu, D.M. (2022). Polyhydroxybutyrate blends: A solution for biodegradable packaging? Int J Biol Macromol; 207:263-77.

[16] Roy, S., Rhim, J.-W. (2020). Carboxymethyl cellulose-based antioxidant and antimicrobial active packaging film incorporated with curcumin and zinc oxide. Int J Biol Macromol; 148:666-76.

[17] Zhao, Y., Sun, H., Yang, B., Weng, Y. (2020). Hemicellulose-Based Film: Potential Green Films for Food Packaging. Polymers; 12.

[18] Realini, C.E., Marcos, B. (2014). Active and intelligent packaging systems for a modern society. Meat Sci; 98:404-19.

[19] Igwe Idumah, C., Nwabanne, J.T., Tanjung, F.A. (2021). Novel trends in poly (lactic) acid hybrid bionanocomposites. Cleaner Mater; 2.

[20] Israni, N., Shivakumar, S. (2019). Polyhydroxyalkanoates in packaging. In: Biotechnological applications of polyhydroxyalkanoates; p. 363-88.

[21] Liu, Y., Qin, Y., Bai, R., Zhang, X., Yuan, L., Liu, J. (2019). Preparation of pH-sensitive and antioxidant packaging films based on kappa-carrageenan and mulberry polyphenolic extract. Int J Biol Macromol; 134:993-1001.

[22] Dai, L., Qiu, C., Xiong, L., Sun, Q. (2015). Characterisation of corn starch-based films reinforced with taro starch nanoparticles. Food Chem; 174:82-8.

[23] da Silva Braga, R., Poletto, M. (2020). Preparation and characterization of hemicellulose films from sugarcane bagasse. Materials (Basel); 13.

[24] Yang, W., Qi, G., Kenny, J.M., Puglia, D., Ma, P. (2020). Effect of cellulose nanocrystals and lignin nanoparticles on mechanical, antioxidant and water vapour barrier properties of glutaraldehyde crosslinked PVA films. Polymers (Basel); 12.

[25] Safitri, A., Sinaga, P., Nasution, H., Harahap, H., Masyithah, Z., Iskandinata, I., et al. (2022). The role of various plastisizers and fillers additions in improving tensile strength of starch-based bioplastics: A mini review. IOP Conf Ser Earth Environ Sci; 1115:012076.

[26] Schmid, M., Müller, K. (2019). Whey protein-based packaging films and coatings. In: Whey Proteins; p. 407-37.

[27] Rezaei, M., Pirsa, S., Chavoshizadeh, S. (2019). Photocatalytic/antimicrobial active film based on wheat gluten/ZnO nanoparticles. J Inorg Organomet Polym Mater; 30:2654-65.

[28] Khan, M.R., Volpe, S., Valentino, M., Miele, N.A., Cavella, S., Torrieri, E. (2021). Active casein coatings and films for perishable foods: Structural properties and shelf-life extension. Coatings; 11.

[29] Mangaraj, S., Yadav, A., Bal, L.M., Dash, S.K., Mahanti, N.K. (2019). Application of biodegradable polymers in food packaging industry: A comprehensive review. J Pack Technol Research; 3:77-96.

[30] Asad, M., Saba, N., Asiri, A.M., Jawaid, M., Indarti, E., Wanrosli, W.D. (2018). Preparation and characterization of nanocomposite films from oil palm pulp nanocellulose/poly (vinyl alcohol) by casting method. Carbohydr Polym; 191:103-11.

[31] Sutay, D., Yağcı, S., Yurtdaş, E., Toptaş, M. (2023). Multiproduct biorefinery from defatted olive mill waste: preparation of hemicellulose-based biodegradable films and instant controlled pressure drop (DIC)-assisted isolation of value-added products. Biomass Convers Biorefin; 10.1007/s13399-023-03739-3.

[32] Jaderi, Z., Tabatabaee Yazdi, F., Mortazavi, S.A., Koocheki, A. (2023). Effects of glycerol and sorbitol on a novel biodegradable edible film based on Malva sylvestris flower gum. Food Sci Nutr; 11:991-1000.

[33] Hyvärinen, M., Jabeen, R., Kärki, T. (2020). The modelling of extrusion processes for polymers—a review. Polymers; 12.

[34] Krepker, M., Zhang, C., Nitzan, N., Prinz-Setter, O., Massad-Ivanir, N., Olah, A., et al. (2018). Antimicrobial LDPE/EVOH layered films containing carvacrol fabricated by multiplication extrusion. Polymers; 10.

[35] Faust, S., Foerster, J., Lindner, M., Schmid, M. (2021). Effect of glycerol and sorbitol on the mechanical and barrier properties of films based on pea protein isolate produced by high-moisture extrusion processing. Polym Eng Sci; 62:95-102.

[36] Bahcegul, E., Akinalan, B., Toraman, H.E., Erdemir, D., Ozkan, N., Bakir, U. (2013). Extrusion of xylans extracted from corn cobs into biodegradable polymeric materials. Bioresour Technol; 149:582-5.

[37] Khan, W.S., Asmatulu, R., Ceylan, M., Jabbarnia, A. (2013). Recent progress on conventional and non-conventional electrospinning processes. Fibers and Polymers; 14:1235-47.

[38] Zhang, C., Li, Y., Wang, P., Zhang, H. (2020). Electrospinning of nanofibers: potentials and perspectives for active food packaging. Compr Rev Food Sci Food Safe; 19:479-502.

[39] Park, S., Park, K., Yoon, H., Son, J., Min, T., Kim, G. (2007). Apparatus for preparing electrospun nanofibers: designing an electrospinning process for nanofiber fabrication. Polymer International; 56:1361-6.

[40] Zehetmeyer, G., Meira, S.M.M., Scheibel, J.M., de Brito da Silva, C., Rodembusch, F.S., Brandelli, A., et al. (2017). Biodegradable and antimicrobial films based on poly(butylene adipate-co-terephthalate) electrospun fibers. Polymer Bulletin; 74:3243-68.

[41] Roy, S., & Rhim, J.-W. (2021). Anthocyanin food colorant and its application in pH-responsive color change indicator films. Critical Reviews in Food Sci Nutri; 61:2297-325.

[42] Guerrero, P., Muxika, A., Zarandona, I., & de la Caba, K. (2019). Crosslinking of chitosan films processed by compression molding. Carbohydr Polym; 206:820-6.

[43] de Matos Costa, A.R., Crocitti, A., Hecker de Carvalho, L.H., Carroccio, S.C., Cerruti, P., & Santagata, G. (2020). Properties of biodegradable films based on poly(butylene succinate) (PBS) and poly(butylene adipate-co-terephthalate) (PBAT) blends. Polymers (Basel); 12.

[44] Marichelvam, M., Jawaid, M., & Asim. (2019). Corn and rice starch-based bio-plastics as alternative packaging materials. Fibers; 7.

[45] Ballesteros-Mártinez, L., Pérez-Cervera, C., & Andrade-Pizarro, R. (2020). Effect of glycerol and sorbitol concentrations on mechanical, optical, and barrier properties of sweet potato starch film. NFS Journal; 20:1-9.

[46] Forssell, P., Lahtinen, R., Lahelin, M., & Myllärinen, P. (2002). Oxygen permeability of amylose and amylopectin films. Carbohydr Polym; 47:125-9.

[47] Vieira, M.G.A., da Silva, M.A., dos Santos, L.O., & Beppu, M.M. (2011). Natural-based plasticizers and biopolymer films: A review. Eur Polym J; 47:254-63.

[48] Wang, C., Gong, C., Qin, Y., Hu, Y., Jiao, A., Jin, Z., et al. (2022). Bioactive and functional biodegradable packaging films reinforced with nanoparticles. J Food Eng; 312:110752.

[49] Fukuda, J., & Hsieh, Y.-L. (2022). Almond shell nanocellulose: Characterization and self-assembling into fibers, films, and aerogels. Ind Crops Prod; 186.

[50] Kampeerapappun, P., Aht-ong, D., Pentrakoon, D., & Srikulkit, K. (2007). Preparation of cassava starch/montmorillonite composite film. Carbohydr Polym; 67:155-63.

[51] Jiang, B., Li, S., Wu, Y., Song, J., Chen, S., Li, X., et al. (2018). Preparation and characterization of natural corn starch-based composite films reinforced by eggshell powder. Materials; 16:1045-54.

[52] Shi, J., Wu, R., Li, Y., Ma, L., Liu, S., Liu, R., et al. (2022). Antimicrobial food packaging composite films prepared from hemicellulose/polyvinyl alcohol/potassium cinnamate blends. Inter J Bio Macromol; 222:395-402.

[53] Gupta, H., Kumar, H., Gehlaut, A.K., Singh, S.K., Gaur, A., Sachan, S., et al. (2022). Preparation and characterization of bio-composite films obtained from coconut coir and groundnut shell for food packaging. J Mater Cycles Waste Manag; 24:569-81.

[54] Silva, M., Bierhalz, A., & Kieckbusch, T. (2009). Alginate and pectin composite films crosslinked with Ca2+ ions: Effect of the plasticizer concentration. Carbohydr Polym; 77:736-42.

[55] El Miri, N., Aziz, F., Aboulkas, A., El Bouchti, M., Ben Youcef, H., & El Achaby, M. (2018). Effect of plasticizers on physicochemical properties of cellulose nanocrystals filled alginate bionanocomposite films. Adv Polym Technol; 37:3171-85.

[56] Wang, S., Ren, J., Li, W., Sun, R., & Liu, S. (2014). Properties of polyvinyl alcohol/xylan composite films with citric acid. Carbohydr Polym; 103:94-9.

[57] Petzold-Welcke, K., Schwikal, K., Daus, S., & Heinze, T. (2014). Xylan derivatives and their application potential – Mini-review of own results. Carbohydr Polym; 100:80-8.

[58] Härdelin, L., Bernin, D., Börjesson, M., Ström, A., & Larsson, A. (2020). Altered thermal and mechanical properties of spruce galactoglucomannan films modified with an etherification reaction. Biomacromolecules; 21:1832-40.

[59] Du, J., Li, C., Zhao, Y., & Wang, H. (2018). Hemicellulose isolated from waste liquor of viscose fiber mill for preparation of polyacrylamide-hemicellulose hybrid films. Inter J Bio Macromol; 108:1255-60.

[60] Zhang, T., Yu, Z., Ma, Y., Chiou, B.-S., Liu, F., & Zhong, F. (2022). Modulating physicochemical properties of collagen films by cross-linking with glutaraldehyde at varied pH values. Food Hydrocolloids; 124.

[61] Bonilla, J., Paiano, R.B., Lourenço, R.V., Bittante, A.M.Q.B., & Sobral, P.J.A. (2021). Biodegradation of films based on natural and synthetic biopolymers using an aquatic system from active sludge. J Poly Environ; 29:1380-95.

[62] Yildirim, S., Röcker, B., Pettersen, M.K., Nilsen-Nygaard, J., Ayhan, Z., Rutkaite, R., et al. (2018). Active packaging applications for food. Compr Rev Food Sci Food Safe; 17:165-99.

[63] Nguyen, T.T., Thi Dao, U.T., Thi Bui, Q.P., Bach, G.L., Ha Thuc, C.N., & Ha Thuc, H. (2020). Enhanced antimicrobial activities and physiochemical properties of edible film based on chitosan incorporated with Sonneratia caseolaris (L.) Engl. leaf extract. Prog Org Coat; 140:105487.

[64] Dey, A., & Neogi, S. (2019). Oxygen scavengers for food packaging applications: A review. Trends in Food Sci Technol; 90:26-34.

[65] Zhang, N., Bi, F., Xu, F., Yong, H., Bao, Y., Jin, C., et al. (2020). Structure and functional properties of active packaging films prepared by incorporating different flavonols into chitosan based matrix. Inter J Bio Macromol; 165:625-34.

[66] Gaikwad, K.K., Singh, S., & Negi, Y.S. (2020). Ethylene scavengers for active packaging of fresh food produce. Environ Chem Lett; 18:269-84.

[67] Xu, D., Chen, T., & Liu, Y. (2021). The physical properties, antioxidant and antimicrobial activity of chitosan–gelatin edible films incorporated with the extract from hop plant. Polymer Bulletin; 78:3607-24.

[68] Lian, H., Shi, J., Zhang, X., & Peng, Y. (2020). Effect of the added polysaccharide on the release of thyme essential oil and structure properties of chitosan based film. Food Packag Shelf Life; 23:100467.

[69] Wu, Z., Wu, J., Peng, T., Li, Y., Lin, D., Xing, B., et al. (2017). Preparation and application of starch/polyvinyl alcohol/citric acid ternary blend antimicrobial functional food packaging films. Polymers; 9.

[70] Kadam, A.A., Singh, S., & Gaikwad, K.K. (2021). Chitosan based antioxidant films incorporated with pine needles (Cedrus deodara) extract for active food packaging applications. Food Control; 124:107877.

[71] Nunes, M.R., de Souza Maguerroski Castilho, M., de Lima Veeck, A.P., da Rosa, C.G., Noronha, C.M., Maciel, M.V.O.B., et al. (2018). Antioxidant and antimicrobial methylcellulose films containing Lippia alba extract and silver nanoparticles. Carbohydr Polym; 192:37-43.

[72] Lukic, I., Vulic, J., & Ivanovic, J. (2020). Antioxidant activity of PLA/PCL films loaded with thymol and/or carvacrol using scCO2 for active food packaging. Food Packag Shelf Life; 26:100578.

[73] Ge, L., Zhu, M., Li, X., Xu, Y., Ma, X., Shi, R., et al. (2018). Development of active rosmarinic acid-gelatin biodegradable films with antioxidant and long-term antibacterial activities. Food Hydrocolloids; 83:308-16.

[74] Mohamad, N., Mazlan, M.M., Tawakkal, I.S.M.A., Talib, R.A., Kian, L.K., Fouad, H., et al. (2020). Development of active agents filled polylactic acid films for food packaging application. Inter J Bio Macromol; 163:1451-7.

[75] He, L., Lan, W., Ahmed, S., Qin, W., & Liu, Y. (2019). Electrospun polyvinyl alcohol film containing pomegranate peel extract and sodium dehydroacetate for use as food packaging. Food Packag Shelf Life; 22:100390.

[76] Zinoviadou, K.G., Koutsoumanis, K.P., & Biliaderis, C.G. (2010). Physical and thermo-mechanical properties of whey protein isolate films containing antimicrobials, and their effect against spoilage flora of fresh beef. Food Hydrocolloids; 24:49-59.

[77] Liu, J., Yong, H., Liu, Y., Qin, Y., Kan, J., & Liu, J. (2019). Preparation and characterization of active and intelligent films based on fish gelatin and haskap berries (Lonicera caerulea L.) extract. Food Packag Shelf Life; 22:100417.

[78] Youssef, A.M., El-Sayed, S.M., El-Sayed, H.S., Salama, H.H., & Dufresne, A. (2016). Enhancement of Egyptian soft white cheese shelf life using a novel chitosan/carboxymethyl cellulose/zinc oxide bionanocomposite film. Carbohydr Polym; 151:9-19.

[79] Zhang, X., Liu, Y., Yong, H., Qin, Y., Liu, J., & Liu, J. (2019). Development of multifunctional food packaging films based on chitosan, TiO2 nanoparticles and anthocyanin-rich black plum peel extract. Food Hydrocolloids; 94:80-92.

[80] Akbar, A., & Anal, A.K. (2014). Zinc oxide nanoparticles loaded active packaging, a challenge study against Salmonella typhimurium and Staphylococcus aureus in ready-to-eat poultry meat. Food Control; 38:88-95.

[81] Moghimi, R., Aliahmadi, A., & Rafati, H. (2017). Antibacterial hydroxypropyl methyl cellulose edible films containing nanoemulsions of Thymus daenensis essential oil for food packaging. Carbohydr Polym; 175:241-8.

[82] Min, S., Harris, L.J., & Krochta, J.M. (2005). Antimicrobial Effects of Lactoferrin, Lysozyme, and the Lactoperoxidase System and Edible Whey Protein Films Incorporating the Lactoperoxidase System Against *Salmonella enterica* and *Escherichia coli* O157:H7. J Food Sci; 70:m332-m8.

[83] Ezati, P., & Rhim, J-W. (2020). pH-responsive chitosan-based film incorporated with alizarin for intelligent packaging applications. Food Hydrocolloids; 102:105629.

[84] Amin, U., Khan, M.K.I., Maan, A.A., Nazir, A., Riaz, S., Khan, M.U., et al. (2022). Biodegradable active, intelligent, and smart packaging materials for food applications. Food Packag Shelf Life; 33:100903.

[85] Li, Y., Ying, Y., Zhou, Y., Ge, Y., Yuan, C., Wu, C., et al. (2019). A pH-indicating intelligent packaging composed of chitosan-purple potato extractions strengthened by surface-deacetylated chitin nanofibers. Inter J Bio Macromol; 127:376-84.

[86] Jamróz, E., Kulawik, P., Krzyściak, P., Talaga-Ćwiertnia, K., & Juszczak, L. (2019). Intelligent and active furcellaran-gelatin films containing green or pu-erh tea extracts: Characterization, antioxidant and antimicrobial potential. Inter J Bio Macromol; 122:745-57.

[87] Jung, J., Puligundla, P., & Ko, S. (2012). Proof-of-concept study of chitosan-based carbon dioxide indicator for food packaging applications. Food Chem; 135:2170-4.

[88] Pucci, A., Signori, F., Bizzarri, R., Bronco, S., Ruggeri, G., & Ciardelli, F. (2010). Threshold temperature luminescent indicators from biodegradable poly(lactic acid)/poly(butylene succinate) blends. J Mater Chem; 20:5843-52.

[89] Vu, C.H.T., & Won, K. (2014). Leaching-Resistant Carrageenan-Based Colorimetric Oxygen Indicator Films for Intelligent Food Packaging. J Agri Food Chem; 62:7263-7.

[90] Vo, T.-V., Dang, T.-H., & Chen, B.-H. (2019). Synthesis of Intelligent pH Indicative Films from Chitosan/Poly(vinyl alcohol)/Anthocyanin Extracted from Red Cabbage. Polymers; 11.

[91] Sun, G., Chi, W., Zhang, C., Xu, S., Li, J., & Wang, L. (2019). Developing a green film with pH-sensitivity and antioxidant activity based on κ-carrageenan and hydroxypropyl methylcellulose incorporating Prunus maackii juice. Food Hydrocolloids; 94:345-53.

[92] Aghaei, Z., Emadzadeh, B., Ghorani, B., & Kadkhodaee, R. (2018). Cellulose Acetate Nanofibres Containing Alizarin as a Halochromic Sensor for the Qualitative Assessment of Rainbow Trout Fish Spoilage. Food Bioprocess Technol; 11:1087-95.

[93] Ardiyansyah, Apriliyanti, M.W., Wahyono, A., Fatoni, M., Poerwanto, B., & Suryaningsih, W. (2018). The Potency of betacyanins extract from a peel of dragon fruits as a source of colourimetric indicator to develop intelligent packaging for fish freshness monitoring. IOP Conference Series: Earth and Environmental Science; 207:012038.

[94] Latos-Brozio, M., & Masek, A. (2020). The application of natural food colorants as indicator substances in intelligent biodegradable packaging materials. Food Chem Toxicol; 135:110975.

[95] Huang, S., Xiong, Y., Zou, Y., Dong, Q., Ding, F., Liu, X., et al. (2019). A novel colorimetric indicator based on agar incorporated with Arnebia euchroma root extracts for monitoring fish freshness. Food Hydrocolloids; 90:198-205.

[96] Moradi, M., Tajik, H., Almasi, H., Forough, M., & Ezati, P. (2019). A novel pH-sensing indicator based on bacterial cellulose nanofibers and black carrot anthocyanins for monitoring fish freshness. Carbohydr Polym; 222:115030.

[97] Ding, L., Li, X., Hu, L., Zhang, Y., Jiang, Y., Mao, Z., et al. (2020). A naked-eye detection polyvinyl alcohol/cellulose-based pH sensor for intelligent packaging. Carbohydr Polym; 233:115859.

[98] Wan, X., He, Q., Wang, X., Liu, M., Lin, S., Shi, R., et al. (2021). Water-soluble chitosan-based indicator label membrane and its response behavior to carbon dioxide. Food Control; 130:108355.

[99] Liang, T., Sun, G., Cao, L., Li, J., & Wang, L. (2019). A pH and NH3 sensing intelligent film based on Artemisia sphaerocephala Krasch. gum and red cabbage anthocyanins anchored by carboxymethyl cellulose sodium added as a host complex. Food Hydrocolloids; 87:858-68.

[100] Wu, S., Wang, W., Yan, K., Ding, F., Shi, X., Deng, H., et al. (2018). Electrochemical writing on edible polysaccharide films for intelligent food packaging. Carbohydr Polym; 186:236-42.

[101] Kato Jr, E.T., Yoshida, C.M.P., Reis, A.B., Melo, I.S., & Franco, T.T. (2011). Fast detection of hydrogen sulfide using a biodegradable colorimetric indicator system. Polymer International; 60:951-6.

[102] Sukhavattanakul, P., & Manuspiya, H. (2020). Fabrication of hybrid thin film based on bacterial cellulose nanocrystals and metal nanoparticles with hydrogen sulfide gas sensor ability. Carbohydr Polym; 230:115566.

[103] Arnon-Rips, H., Sabag, A., Tepper-Bamnolker, P., Chalupovich, D., Levi-Kalisman, Y., Eshel, D., et al. (2020). Effective suppression of potato tuber sprouting using polysaccharide-based emulsified films for prolonged release of citral. Food Hydrocolloids; 103:105644.

[104] Ezati, P., Khan, A., Priyadarshi, R., Bhattacharya, T., Tammina, S.K., & Rhim, J-W. (2023). Biopolymer-based UV protection functional films for food packaging. Food Hydrocolloids; 142:108771.

[105] Koirala, P., Nirmal, N.P., Woraprayote, W., Visessanguan, W., Bhandari, Y., Karim, N.U., et al. (2023). Nano-engineered edible films and coatings for seafood products. Food Packag Shelf Life; 38:101135.

[106] Yu, Y., Zheng, J., Li, J., Lu, L., Yan, J., Zhang, L., et al. (2021). Applications of two-dimensional materials in food packaging. Trends in Food Sci Technol; 110:443-57.

[107] Channa, I.A., Ashfaq, J., Siddiqui, M.A., Chandio, A.D., Shar, M.A., & Alhazaa, A. (2022). Multi-Shaded Edible Films Based on Gelatin and Starch for the Packaging Applications. Polymers [Internet]; 14.

[108] Gascon, M. (2007). Masking agents for use in foods. In: editor^editors (Ed.), Modifying Flavour in Food: Woodhead Publishing; 232-42.

[109] Gaikwad, K.K., Singh, S., & Lee, Y.S. (2018). Oxygen scavenging films in food packaging. Emerg Conta; 16:523-38.

[110] Rhim, J-W. (2004). Physical and mechanical properties of water resistant sodium alginate films. LWT - Food Sci and Technol; 37:323-30.

[111] Liu, C., Huang, J., Zheng, X., Liu, S., Lu, K., Tang, K., et al. (2020). Heat sealable soluble soybean polysaccharide/gelatin blend edible films for food packaging applications. Food Packag Shelf Life; 24:100485.

[112] Lu, Y., Luo, Q., Chu, Y., Tao, N., Deng, S., Wang, L., et al. (2022). Application of Gelatin in Food Packaging: A Review. Polymers [Internet]; 14.

[113] Putranto, A.W., Sakhbani, M.M., Khoir, N.H., Mutiarani, N., Susilo, B., & Hermanto, M.B. (2021). Design and performance evaluation of edible film printing machine based on automatic casting knife. IOP Conference Series: Earth and Environmental Science; 733:012006.

[114] Liu, B.-Y., Xue, C.-H., An, Q.-F., Jia, S.-T., & Xu, M.-M. (2019). Fabrication of superhydrophobic coatings with edible materials for super-repelling non-Newtonian liquid foods. Chem Eng J; 371:833-41.

[115] Huang, S., Wang, G., Lin, H., Xiong, Y., Liu, X., & Li, H. (2021). Preparation and dynamic response properties of colorimetric indicator films containing pH-sensitive anthocyanins. Sensors and Actuators Reports; 3:100049.

[116] Wang, Q., Chen, W., Zhu, W., McClements, D.J., Liu, X., & Liu, F. (2022). A review of multilayer and composite films and coatings for active biodegradable packaging. npj Sci of Food; 6:18.

[117] Ordoñez, R., Atarés, L., & Chiralt, A. (2022). Biodegradable active materials containing phenolic acids for food packaging applications. Compr Rev Food Sci Food Safe; 21:3910-30.

[118] Sothornvit, R., & Krochta, J.M. (2005). Plasticizers in edible films and coatings. In: Innovations in Food Packaging: Academic Press; 403-33.

[119] Bhatia, S., Al-Harrasi, A., Al-Azri, M.S., Ullah, S., Makeen, H.A., Meraya, A.M., et al. (2022). Gallic Acid Crosslinked Gelatin and Casein Based Composite Films for Food Packaging Applications. Polymers; 14.