



Exploring the Role of Phytochemical Additives in Enhancing the Properties of Gelatin-Chitosan Films: A Review

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Abstract

The extensive use of plastic packaging has significantly contribute to the issue of plastic pollution. To address this issue, there is an increasing demand for eco-friendly packaging solutions and researchers are exploring the use of biodegradable materials like gelatin and chitosan for food packaging. Adding plant phytochemicals to gelatin and chitosan films has garnered significant interest because of their phenolic content and antioxidant properties since studies on biodegradable films reveal that the mechanical properties, biodegradability, and antimicrobial activities of these films can be enhanced by adding phytochemicals. In this review, we focus on how different phytochemicals influence the antioxidant and antimicrobial activities of gelatin and chitosan-based biodegradable films and discussion on the possibilities of phyto chemical addition in these films.

Keywords: Biodegradable packaging, gelatin-chitosan films, phytochemicals

Introduction

The world has seen a dramatic rise in plastic production and usage in recent years with an estimated global production of nearly 9200 million metric tons (Walker & Fequet, 2023), and it is predicted that this number will double within the next two decades. The popularity of petroleum-based plastic materials is due to their easy production, availability and hence are widely used across several sectors, including transportation, electronics, agriculture, construction, packaging, the medical

and health industry, sports, and recreation (Dahlbo, Poliakova, Mylläri, Sahimaa, & Anderson, 2018). However, despite their benefits, plastic usage has harmful impacts on the environment, which ultimately affects human health. Plastic takes many years to undergo any physical, chemical, or biological degradation, causing significant concern for disposal (O'Brine & Thompson, 2010). It is estimated that only about 18% of plastic waste is recycled, with 24% being incinerated and the remaining 58% being dumped in landfills or oceans. This leads to pollution of the land, air, and water (Chamas et al., 2020). Plastic waste accumulates in ecosystems, and over time, breaks down into microplastics that have detrimental effects on soil, water, and aquatic and terrestrial ecosystems (Karbalaeei, Hanachi, Walker, & Cole, 2018; Tan, Wang & Sun, 2021; Xu, Chen, & Liu, 2021).

The concern regarding the negative impacts of plastic on the environment and increasing waste generation rates have prompted research to explore new materials made from natural resources that are convenient, safer, and cheaper to produce. With the growing awareness of the necessity for eco-friendly food packaging, industries are working to develop biodegradable resources that are safe. Bioplastics made from renewable biomass are considered a viable long-term replacement for plastics derived from petrochemicals, as they have the potential to enhance food safety and quality (Said, Howell & Sarbon, 2023). Biopolymers such as cellulose, starch, chitin, or chitosan, proteins from animals and plants, fats, and waxes are found to be safe and suitable for the production of edible packaging films. These materials have various benefits, such as soil degradability, water and/or O₂ barrier properties, and safety (Mellinas et al., 2016) and hence demand for packaging materials that are replenishable, recoverable, and compostable has increased considerably.

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Plant extracts are a potential source of phytochemicals that could be incorporated to improve the functional traits of biodegradable packaging films (Hu, Yao, Qin, Yong, & Liu, 2020). The addition of phytochemicals from natural plant materials not only maintains the texture, colour, odour, and flavour of food products but also improves their functional traits, such as antioxidant, antifungal, and antimicrobial activities. By incorporating these extracts, it is also possible to enhance the mechanical and barrier properties of the films. Hence active packaging film can be an alternate choice to traditional packaging materials derived from petrochemical, this minimizing environmental pollution. This review describes the effects of incorporating various types of plant-sourced phytochemicals on the mechanical and barrier properties of biopolymers-based packaging films. These effects depend on the type and concentration of the extract. The structural and functional attributes of biopolymers are influenced by their physical or chemical interactions with extracts (Mir, Dar, Wani, & Shah, 2018).

Bio-based polymers

Polymers are natural or manmade compounds made up of very big molecules known as macromolecules, which are multiples of smaller chemical units known as monomers (Cazón & Vázquez, 2020). Polymers include many of the components found in living beings and serve as the basis for many minerals and man-made compounds (Harika, Sunitha, Maheshwar, & Rao, 2012). Bio-based polymers are often obtained from renewable sources (algae, microorganisms, plants, animals, etc.) or they can be synthesized directly or by polymerization.

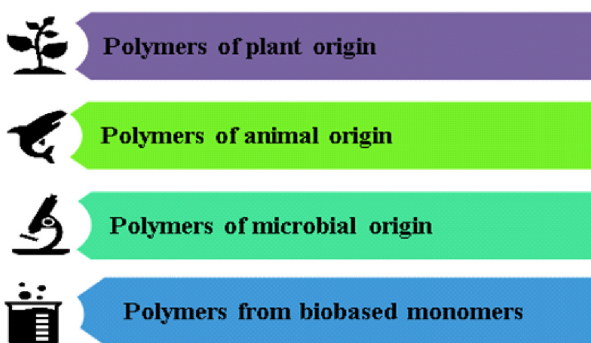


Fig. 1. Classification of bio-based polymers

The bio-based polymers can be categorized according to their origin, (Fig. 1) Polymers such as starch, lignin, and cellulose originate from plant sources. Starch can be used as an alternative to plastic for making packaging films (Diyana et al., 2021). Cellulose-based polymers have also been used in various fields, including textiles, packaging, and medical implants (Klemm et al., 2018). The polymers such as chitin, collagen, and gelatin are derived from animal-based sources. The edible nature of these materials makes them a safer option for food packaging (Mellinas et al., 2016). The addition of phytochemicals, gelatin and chitosan films offers promising properties for active packaging. Chitosan displays antimicrobial activity against gram-positive and gram-negative bacteria (Malinowska-Pańczyk, Staroszczyk, Gottfried, Kolodziejska, & Wojtasz-Pajak, 2015). Though gelatin films have drawbacks in terms of their gas barrier and water barrier properties, these limitations can be addressed by mixing them with chitosan to produce composite and bilayer films (Wang, Ding, Ma, & Zhang, 2021). Such films offer the potential for enhanced mechanical characteristics, making them an ideal option for packaging foods. Additionally, the use of gelatin and chitosan in these films can maintain the quality attributes of the food commodities. Bio-based polymers from microorganisms are derived from microbes like yeast and bacteria and examples include polyhydroxyalkanoates (PHAs) and bacterial cellulose. PHAs have a wide range of applications in medical implants and food packaging (Ladhari, Vu, Boisvert, Saidi, & Nguyen-Tri, 2023), while bacterial cellulose is GRAS-compliant and can be used as a food packaging material (Lin, Liu, Shen, Chen, & Yang, 2020).

Polymers synthesized from bio-based monomers include polylactic acid, polyglycolide, polybutylene succinate, polycaprolactone (PCL), Polybutylene adipate terephthalate, and polylactic acid (PLA), which are biodegradable polymers and are derived from renewable resources (Williams & Hillmyer, 2008). PLA is synthesized from lactic acid, which is produced by fermentation of sugar beets, corn, and other crops. It has generated significant interest due to its very high mechanical properties, suitability for biological use, and biodegradability. On the other hand, PCL is synthesized from ϵ -caprolactone, which is derived from crude oil or renewable sources such as corn or vegetable oils. PCL has a low melting point and good mechanical properties, which makes it suitable for various biomedical

applications (Patel, Bastioli, Marini, & Würdinger, 2005). Polyglycolide (PGA) and polylactide-co-glycolide (PLGA) are copolymers of lactic acid and glycolic acid and are widely used in the medical industry as a material for sutures and in drug delivery systems. PGA has excellent mechanical properties but is relatively hydrophobic, while PLGA has improved hydrophilicity and biodegradability due to the presence of glycolic acid in its polymer backbone (Siracusa & Rosa, 2018). PBS, or polybutylene succinate, is a biodegradable polymer developed from 1,4-butanediol and succinic acid and is popular due to its excellent mechanical properties, and high decomposability making it suitable for various uses including biomedical equipment, packaging, and textiles (Patel et al., 2005). PBAT, or polybutylene adipate terephthalate is a biodegradable co-polyester synthesized from adipic acid, terephthalic acid, and butanediol. It can be effectively processed independently or blended through various conventional manufacturing techniques, including extrusion, injection molding, and blown film extrusion, due to its good thermal stability and mechanical properties (Jian, Xiangbin, & Xianbo, 2020).

Chitosan and Gelatin: Biopolymers for Sustainable Food Packaging.

Chitosan

Chitosan, a naturally occurring biopolymer extracted from chitin, is a potential substitute for synthetic materials, particularly in food packaging applications. Chitin, the second-most abundant polysaccharide in nature, is transformed into chitosan, a linear polymer, *via* deacetylation (De Azeredo, Britto, & Assis, 2011). The antibacterial properties of chitosan against various microorganisms, including fungi, algae, and some bacteria, make it an attractive biomaterial (Tsai & Su, 1999). Moreover, chitosan exhibits excellent film-forming characteristics, such as mechanical strength, water barrier properties, selective CO₂ and O₂ permeability, and antibacterial properties (Cazón & Vázquez, 2020).

Gelatin

The capacity of gelatin to form films is due to its amphiphilic nature, which permits it to form hydrogen bonds with water and hydrophobic interactions with air or other hydrophobic surfaces (Arvanitoyannis & Kassaveti, 2008). Gelatin films

have exceptional mechanical strength due to their high elasticity and tensile strength, making them suitable for a variety of uses (Liu et al., 2021). Furthermore, gelatin films are biodegradable and non-toxic, which makes them a potential alternative to man-made polymers in many fields. Several studies have investigated the film-forming properties of gelatin and its composites with other materials, including polysaccharides and synthetic polymers, to enhance their properties and expand their applications (Sánchez-González, Vargas, González-Martínez, Chiralt, & Chafer, 2011)

Gelatin-Chitosan Composite and Bilayer Films

Gelatin-chitosan composite films have been increasingly studied as a potential biomaterial since it has distinctive characteristics that make them appropriate for various applications. The incorporation of biologically active compounds, such as plant extracts, into the film is possible due to the compatibility of gelatin and chitosan, leading to the innovation of bio-active packaging materials with promising use in the pharmaceutical and food industries.

Studies have examined the fabrication and characterization of gelatin-chitosan bilayer films (Luangapai & Iwamoto, 2023). Bilayer films composed of gelatin and chitosan nanoparticles that display positive changes in mechanical strength compared to monolayer films could be used for the sustained release of bioactive compounds such as turmeric and curcumin. The significance of varying the gelatin-to-chitosan ratio on the characterization of bilayer films loaded with cinnamon essential oil was determined by Tan et al. (2021) and it is showed that an increase in gelatin content in the films improved their mechanical strength while increasing chitosan content enhanced their barrier properties and water resistance. The bilayer films also showed excellent antimicrobial activity against *S. aureus* and *E. coli*.

Incorporation of phytochemicals into Gelatin-Chitosan composite films

The addition of plant extracts into the composite film can provide various benefits, such as enhancing the mechanical and barrier strength of the film, reducing microbial growth, and improving the shelf stability of food items. Additionally, the use of plant extracts in the film can also have antioxidant and antimicrobial properties, which can help in preventing the oxidation of food and the growth of

pathogenic microorganisms. Composite films made of chitosan and gelatin have shown great potential as a regenerative substitute for conventional packaging materials. These composite films can also be modified to incorporate natural plant extracts, or phytochemicals, with various bioactive properties that offer additional functionality to the packaging material. Several studies have explored the effectiveness of incorporating different plant extracts in combination with gelatin-chitosan composite films. (Sánchez et al., 2011). Prepared composite films from gelatin and chitosan loaded with thyme essential oil, exhibited excellent antioxidant and antimicrobial activity. Similarly, Chin et al. (2017) developed composite films of chitosan and gelatin with added aloe vera extract which enhanced barrier properties and mechanical strength. Additionally, the films showed excellent antioxidant activity and could potentially be used as an active packaging material in the food industry. Haghighi et al. (2019) investigated the effect of spice essential oil addition into the gelatin chitosan composite film and the films exhibited enhanced UV barrier properties, along with increased antimicrobial and antioxidant activities. Kola & Carvalho (2023) reported the addition of plant extracts to gelatin-chitosan composite films which offers various benefits, including improved mechanical and barrier properties, reduced microbial growth, and enhanced antioxidant and antimicrobial activities.

Broad classification of phytochemicals incorporated into edible films

Phenolic compounds

Phenolic compounds are the major compounds found in many plant parts, including fruits, stems, and leaves. This group of compounds includes, hydroxyphenyl acetic acids, hydroxybenzoic acids, and hydroxycinnamic acids and has been widely studied for its food preservation and pharmacological properties (Ordoñez, Atarés, & Chiralt, 2022). Nevertheless, the presence of phenolic compounds in packaging compositions may influence the sensory attributes of films and potentially modify their mechanical properties (Soto-Vaca, Gutierrez, Losso, Xu, & Finley, 2012; Choi, Choi, Lee, & Chang, 2022). Phenolic-loaded films have been found to exhibit antibacterial and antioxidant capacities, with significant variations depending on the content of the compounds (Azeredo & Waldron, 2016). Phenolic compounds possess antioxidant characteristics

due to their chemical structure, which enables them to donate hydrogen atoms or electrons, bind metal cations, or scavenge free radicals (Lopez-de-Dicastillo, Alonso, Catala, Gavara, & Hernandez-Munoz, 2010). Furthermore, their pro-oxidative properties and capability to alter the surface charge and hydrophobicity of gram-positive bacterial cells, inducing cracks and cytoplasmic deposits, have also been reported (Cueva et al., 2010). The phenolic compounds undergo hydrophobic interactions with the hydrophobic region of gelatin, due to the numerous hydrophobic groups (Rasid, Nazmi, Isa, & Sarbon, 2018). Study conducted by Shan et al. (2024), with incorporation of green tea extract into gelatin films demonstrated a significant increase in tensile strength, which was attributed to the stable pentacyclic and hexacyclic ring structures of polyphenolic compounds present in the green tea extract, that hindered the free rotation of bonds in the films.

Flavonoids

Flavonoids are compounds of plant origin and are known to possess antibacterial properties. Since, plants have an innate immunity comprising multiple layers of defense mechanisms to impede the spread of illnesses (Górniak, Bartoszewski, & Króliczewski, 2019), flavonoid compounds, including flavone, galangin, apigenin, and isoflavones, glycosides, flavonol, flavanones, and chalcones have demonstrated potent antibacterial effects (Rukayadi, Han, Yong, & Hwang, 2010). Therefore, the antibacterial properties of flavonoids make them attractive candidates for incorporation into packaging films.

Tannins

Tannins rank as the second most prevalent group of polyphenolic compounds and is found abundantly in plant-based food sources. Additionally, more than 90% of commercial tannins are proanthocyanidins, a type of condensed tannin (Missio, Gatto, & Tondi, 2019). The utilization of tannins in nanocellulose films has been observed to enhance the hydrophobicity of the films. It is found to improve the thermal stability, surface structure, oxygen barrier, water barrier, and vapour barrier properties of chitosan, gelatin, and methylcellulose composite films, as well as the tensile strength of pure gelatin films (Kamari & Phillip, 2018). Moreover, gelatin films containing tannic acid have exhibited antimicrobial properties against *S. aureus* and *E. coli* (Leite-Legatti et al., 2012) and have also demonstrated antioxidant

activity (Widsten, Cruz, Fletcher, Pajak, & McGhie, 2014).

Alkaloids

Bioactive compounds, such as plant alkaloids, have potential applications in the production of packaging films. Studies have demonstrated that alkaloids can enhance barrier properties of film against water vapor and oxygen (Gutiérrez-Grijalva, López-Martínez, Contreras-Angulo, Elizalde-Romero, & Heredia, 2020). Moreover, the use of plant alkaloids, such as berberine, in combination with gelatin and chitosan has been reported to have antibacterial and antiviral activity (Pan et al., 2015). Therefore, plant alkaloids offer a promising alternative for preparation of ecofriendly and sustainable packaging materials with enhanced antimicrobial and antioxidant activity.

Properties of gelatin and chitosan composite films incorporated with phytochemicals

The addition of plant phytochemicals to gelatin-chitosan composite films can also enhance their functionalities. Flavonoids, phenolic compounds, and essential oils are examples of phytochemicals that exhibit antioxidant and antimicrobial properties. These characteristics can be beneficial in prolonging the shelf life of food products. The incorporation of thyme essential oil into gelatin-chitosan composite films was reported by Qin, Li, Zhang, Meng, & Zhu (2024), in which the films exhibited excellent antimicrobial activity against *E. coli* and *S. aureus* and improved antioxidant properties. Wang et al. (2021) reported the development of gelatin-chitosan composite films incorporated with rutin, a flavonoid found in many plants. The films exhibited improved mechanical properties, and also showed good compatibility with orange juice.

Water vapor barrier properties

Maintaining the quality and shelf life of food products is dependent on the water vapor barrier properties of packaging films. The prevention of moisture migration between the packaged goods and the environment is critical in achieving this objective (Kofinas, Cohen, & Halasa, 1994). Roy & Rhim (2021a) studied the effect of adding rutin and cinnamon essential oil to gelatin-chitosan composite film on its water vapor permeability and they observed that incorporation of rutin increased the film's WVTR slightly by forming porous structures

in the film. Similarly, Xu et al. (2021) reported, *Humulus lupulus* flower-extract added chitosan - gelatin films had a lower WVTR than the pure chitosan-gelatin films, possibly due to the homogeneous and dense structure of the composite film. The water vapor permeability of gelatin-furcellaran composite films was studied by Nowak et al. (2023). Both dry and fresh rosemary leaf extract were added into the films and it was found that the fresh leaf extract reduced the WVTR of the film more than the dry leaf extract by promoting cross-linking between proteins and phenolic compounds with higher quantities of hydroxyl groups (OH). Likewise, Wang et al. (2023) found that the addition of watermelon rind extract into chitosan-guar film decreased WVTR. However, some researchers have also reported a negative impact associated with the addition of plant extracts into gelatin-chitosan films. da Nóbrega et al. (2022) noticed that addition of 2% *Malpighia emarginata* extract increased the permeability to water vapor compared to control gelatin films.

Oxygen barrier properties

Oxygen is one of the most important factors affecting the shelf life and quality of food products. Therefore, the development of films with improved oxygen barrier properties is crucial in the food packaging industry. There are numerous studies exploring the application of plant extracts as natural additives in gelatin-chitosan composite films to enhance their oxygen barrier properties.

Several studies have reported the successful incorporation of plant extracts such as green tea extract, grape seed extract, and cinnamon essential oil into gelatin-chitosan composite films, leading to improved oxygen barrier properties (Wang et al., 2023). Similarly, Ștefănescu, Socaciu, & Vodnar (2022) reported that the incorporation of 5% blueberry extract into the films led to a 21% reduction in oxygen permeability, while the inclusion of 5% parsley extract and 5% red grape extract resulted in decreases of permeability by 16% and 14%, respectively. Moreover, Xu, et al. (2021) reported that hop plant extract incorporated into gelatin-chitosan film had a higher oxygen transmission rate (OTR) than chitosan and gelatin films.

Mechanical characteristics

The maximum stress a material can endure before breaking is known as tensile strength, whereas elongation at break (EAB) is an indicator of a film's

stretchability or capacity to deform under pressure (Chen et al., 2017). The integration of plant phytochemicals into gelatin-chitosan composite films can affect their mechanical properties. Rambabu, Bharath, Banat, Show, & Cocolletzi (2019) found that incorporating mango leaf extract into chitosan films improved their tensile strength and elongation at break. Siracusa (2012) found that the addition of plant phytochemicals, such as polyphenols and carotenoids, into gelatin-chitosan composite films improved mechanical strength, such as elongation at break and tensile strength. However, Roy & Rhim (2021a) reported that adding cinnamon essential oil and rutin into a gelatin-chitosan composite film decreased its tensile strength and elongation at break. Siracusa (2012) reported that the addition of plant phytochemicals, such as polyphenols and carotenoids, into gelatin-chitosan composite films improved mechanical strength, such as elongation at break and tensile strength. Therefore, the effects of plant phytochemicals on the mechanical properties of gelatin-chitosan composite films may vary depending on the type and concentration of the phytochemicals used.

Bonilla, Poloni, & Sobral (2018) explored the effects of adding ginger essential oil and eugenol to gelatin-chitosan films and observed enhanced tensile strength in the films with eugenol when compared to the control sample. Likewise, Hanani, Yee, & Nor-Khaizura (2019) found that the inclusion of pomegranate peel powder in pure gelatin films resulted in improved tensile strength which could be attributed to the interaction between plant polyphenols and pectin, which enhances the film's tensile strength (Kanatt, 2012). Wang et al. (2022) investigated the effect of curcumin on the mechanical properties of gelatin-chitosan films. They found that increasing concentrations of curcumin resulted in films with higher elongation at break and tensile strength. Additionally, the incorporation of haskap berries extract into fish gelatin films showed an increase in both tensile strength and elongation at break as the concentration of the extract increased (Liu et al., 2019). However, there was a decrease in the tensile strength of gelatin films with the addition of litchi shell extract, from 21 MPa to 8.17 MPa, while the elongation at break improved from 5.5% to 64% (Guo, Shao, Ma, Zhang, & Lu, 2023). The main reason for these results could be that the litchi shell extract included many organic components resulting in the loose structure of the films and a decrease in tensile strength.

Antioxidant and antimicrobial properties

There is currently a growing interest in the antioxidant and antibacterial properties of packaging films, driven by their potential to extend shelf life and prevent microbial attacks and enzymatic browning during the storage of food products (Krishna, Dhanya, Shanty, Raghu, & Mohanan, 2023). Previous studies have explored the antibacterial efficacy of various film types, including gelatin-chitosan composites, capsaicin-loaded gelatin and chitosan films, and rosemary essential oil-incorporated gelatin films, against bacterial strains such as *L. monocytogenes*, *E. coli*, *S. putrefaciens*, *V. parahaemolyticus*, *P. aeruginosa*, and *E. faecalis* (Wang et al., 2023). The antibacterial properties of plant extracts, particularly flavonoids, are attributed to their interaction with the phospholipid bilayer of bacterial cell membranes (Rubini et al., 2020; Roy & Rhim, 2021a). In addition to antibacterial properties, the incorporation of natural compounds such as grape seed extract and pomegranate extract into gelatin films has been demonstrated to enhance their antioxidant capabilities. This enhancement is further supported by the belief that peptide bonds in gelatin and the OH and NH₂ functional groups in chitosan contribute to their respective antioxidant activities (Xie, Xu, & Liu, 2001; Roy & Rhim, 2021a; Roy & Rhim, 2022b). The antioxidant potential of chitosan films substantially increased on addition of 4 wt% watermelon rind extract and also resulted in increased DPPH radical scavenging activity, rising from 20.2% to 84%. This improvement is attributed to the abundant presence of bioactive compounds, such as polyphenols in the watermelon rind extract, which possess the ability to capture free radicals and interrupt free radical chain reactions (Wang et al., 2023). Furthermore, Shan et al. (2024) reported that the addition of green tea extract significantly enhanced the antioxidant activity of gelatin and alginate films, as indicated by increased 2,2-Diphenyl-1-picrylhydrazyl scavenging activity. This improvement can be attributed to the presence of phenolic compounds in green tea extract, which have the capacity to disrupt chain oxidation reactions, donate hydrogen atoms, and act as receptors for free radicals.

Packaging applications of gelatin-chitosan composite films incorporated with phytochemicals

The recent investigations have been centered on the utilization of gelatin-chitosan films that contain

phytochemicals to improve the quality and shelf life of diverse food products, including meat, fish, fruits, and vegetables. For instance, Lee, Lee, Yang, & Song (2016) added thyme essential oil to skate skin gelatin film to store chicken tender loins, which resulted in increased storage stability and inhibition of *L. monocytogenes* and *E. coli*. Chitosan-gelatin-tannic acid films were developed to preserve fresh cut apples, resulting in low weight loss, inhibition of browning and lipid oxidation and malondialdehyde degree (Zhang et al., 2021). Grass carp wrapped in gelatin-chitosan film containing oregano essential oil exhibited better inhibitory activity against various microorganisms, including *S. aureus*, *E. coli*, *Bacillus subtilis*, and *Salmonella enteritidis* (Wu et al., 2016). Additionally, chitosan-gelatin film containing thyme essential oil showed better antimicrobial activity against *L. monocytogenes* in black radish (*Jovanoviæ*, Klaus, & Niksiæ, 2016). In addition, the use of chitosan-based composite films containing grape seed extract as packaging for bread samples has been shown to decrease mold growth in comparison to untreated samples (Tan et al., 2021). Recently, Lu et al. (2022) reported that incorporating papain into gelatin film improved the quality of frozen dough bread by enhancing bread volume and

delaying detrimental deterioration during frozen storage. This study also recorded that the gelatin and papain films effectively protected the frozen dough by significantly decreasing the amount of thiol groups (-SH) and the degree of depolymerization of the glutenin macropolymer. These findings highlight the potential of using gelatin-chitosan films incorporating plant bioactives to enhance food preservation and quality.

Al-Maqtari et al. (2023) developed chitosan-gelatin composite films added with *Pulicaria jaubertii* extract and grape seed extract with improved antioxidant and antibacterial properties. Similarly, Zhang, Liang, Li, & Kang (2020) prepared gelatin-chitosan composite films containing tarragon essential oil, which improved the antibacterial properties of the film against *S. aureus* and *E. coli*. Gelatin film coating containing 15% gelatin, 30% glycerol, and 1% green tea extract exhibited considerable reduction in the TBARS value of fresh meat sausage during storage (Hamann et al., 2022). The use of plant phytochemicals in chitosan-gelatin composite films for food packaging has great potential as the world moves towards more sustainable and eco-friendly future, the demand for biodegradable and environ-

Table 1. Examples of phytochemicals incorporated in gelatin/chitosan-based films

Type of phytochemical	Type of polymer	Effectiveness/Activities	Reference
Banana peel extract	Chitosan	Improvement in antioxidant activity	Zhang et al. (2019)
Leaf Extract from <i>Sonneratia caseolaris</i> Engl	Chitosan	Improvement in antioxidant and antimicrobial properties	Nguyen et al. (2020)
Leaf extract of <i>Piper betle</i> Linn.	Chitosan	Improvement in antioxidant and antimicrobial properties	Thuong, Ngoc Bich, Thuc, Quynh, & Minh (2019)
Eugenol and ginger essential oils	Gelatin / Chitosan	Improvement in antioxidant and antimicrobial properties	Bonilla et al. (2018)
Clove, cinnamon, pink, nutmeg citronella and thyme essential oils	Gelatin / Chitosan antimicrobial properties	Improvement in antioxidant and antimicrobial properties	Haghighi et al. (2019)
Chinese-hawthorn	Gelatin / Chitosan	Improvement in antioxidant and antimicrobial properties	Kan et al. (2019)
Hop plant extract	Gelatin-Chitosan	Improvement in antioxidant and antimicrobial properties	Xu, et al. (2021)
Cinnamon essential oil and rutin	Gelatin -Chitosan	Improvement in antioxidant and antimicrobial properties	Roy & Rhim (2021a)
Leaf extract of mango tree	Chitosan-Gelatin	Improvement in antioxidant and antimicrobial properties	Rambabu, Bharath, Banat, Shaw, & Cocoltzi (2019)

mentally friendly materials is on the rise. Incorporating plant phytochemicals into gelatin-chitosan composite films not only offers a solution to the issue of plastic waste but also provides additional benefits, including antimicrobial and antioxidant properties.

Challenges and future perspectives

Although significant improvements have occurred in this field of biodegradable films, the utilization of natural bioactive substances in food packaging faces several challenges. This includes thermal and oxidative instability and water solubility. Additionally, these substances are sensitive to environmental factors such as oxygen, heat, and light, leading to a potential loss of their activity. Another issue related to the incorporation of plant extracts include unpleasant taste, possible allergic reactions, and high production costs (Kola & Carvalho, 2023). However, ongoing research in this area aims to overcome these challenges and advance the future usage and commercialization of such bioactive substances. Looking ahead, the development of gelatin-chitosan composite films based on phytochemicals holds great promise for creating highly functional packaging materials. These films have the potential for applications beyond food packaging, such as in the medical field for drug delivery systems or wound dressings. Moreover, they could find utility in the agricultural industry to enhance the shelf life of fresh produce, reduce food waste, and improve overall profitability.

Conclusion

The incorporation of natural plant extracts into composite films of chitosan and gelatin demonstrates significant potential for creating biologically active packaging materials with antioxidant and antimicrobial properties. These composite films, suitable for the food packaging industry, aid in extending the shelf life of food products and reducing food waste. Adding plant phytochemicals to gelatin-chitosan films enhances their biodegradability, mechanical characteristics, barrier properties, and antibacterial activity. This innovative approach also facilitates the conversion of agroindustry waste into a valuable resource, aligning with the circular design strategy that promotes sustainability and waste reduction by repurposing waste materials. Utilizing biodegradable materials like gelatin and chitosan in food packaging helps

address the significant environmental concern of plastic waste. Therefore, integrating plant phytochemicals into gelatin-chitosan films has the potential to revolutionize the food packaging industry by offering sustainable and environmentally friendly solutions.

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