CHAPTER

Plant extracts as packaging aids

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11.1 Introduction

In the last few years, several new ideas have been developed for food packaging. Consumers are demanding more and more mildly preserved convenience foods with better quality. Moreover, there have been changes in retail and distribution practices such as the central implementation of operations, new trends and internationalization of markets. Consequently, a range of different products with different temperature requirements has increased distribution distances and longer storage times and have also placed great demands on the food packing sector (Han, Ruiz-Garcia, Qian, & Yang, 2018; Silberbauer & Schmid, 2017). The ability to extend the shelf life of food products is limited to traditional packaging concepts (Wyrwa & Barska, 2017).

11.1.1 Smart packaging

Smart packaging, which includes active and intelligent packaging, is an enhancement to traditional packaging functions and is anticipated to be the future of food packaging solutions (Lloyd, Mirosa, & Birch, 2019).

11.1.1.1 Active packaging

Active packaging is an innovative approach that can be described as a form of packaging that changes packaging conditions to increase shelf life or enhance safety or sensory properties while maintaining food quality (Wyrwa & Barska, 2017; Yildirim et al., 2018). Nowadays, the development of food packaging with the idea of incorporating active compounds into packaging materials or their circumstances known as "active packaging" has been evolved (Adilah, Jamilah, Noranizan, & Hanani, 2018; Mir et al., 2017). The researchers have gained interest in this innovation because of the need to increase the shelf life of food, preserve food and food quality, and develop organoleptic functionality. In addition, eco-friendly active packaging and natural preservatives could provide better solutions to health and environmental problems (Guillard et al., 2018). The packaging cannot provide information on food storage history, including changes in temperature, the stability of the package, the environmental conditions and food spoil, even though the development of the

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packaging industry guaranteed quality of food. Efforts are also being made to build a framework capable of informing customers of food quality and health, and the implementation of intelligent packaging systems is one of the most recent approaches for this purpose (Eskandarabadi et al., 2019; Yousefi et al., 2019).

11.1.1.2 Intelligent packaging

Another modern type of packaging that characterizes the ability to monitor the condition of packaged food or the environment by providing information on various factors during the transport and stocking is intelligent packaging (Pereira de Abreu, Cruz, & Paseiro Losada, 2012).

11.1.2 Plant extract

In recent years, because of the natural compounds they contain, interest in plant extracts has increased. The biological function of the substances has gained economic significance and has contributed to the growing use of these plant extracts in natural therapies and alternative medicines (Yilar, Kadioglu, & Telci, 2018). For many years, plant extracts have been used for various purposes. As a natural source of antioxidant and antimicrobials, they have recently become a widespread interest. Plant extracts are especially valuable because they are relatively safe, improve food shelf-life, are generally have embraced by consumers and can be used for a variety of different applications due to their potential (Rakholiya, Kaneria, & Chanda, 2013). Plant extract can be combined into the films due to their phenolic ingredients with antioxidant and antimicrobial activities (Lee, Yang, Lee, & Song, 2016). Essential oils (EOs) extracted from plants or spices are rich sources of biologically active compounds such as terpenoids and phenolic acids (Ruiz-Navajas, V.-M., Sendra, Perez-Alvarez, & Fernández-López, 2013). EOs extracted from thyme (Karabagias, Badeka, & Kontominas, 2011), cinnamon (Bonilla & Sobral, 2016; Hu, Wang, Xiao, & Bi, 2015), rosemary (Eskandarabadi et al., 2019) and oregano (Lee et al., 2016) showed significant antimicrobial activities versus various microorganisms. It has been long recognized that some of the EOs have antioxidant properties (Alexandre, Lourenço, Bittante, Moraes, & Sobral, 2016; Bhavaniramya, Vishnupriya, Al-Aboody, Vijayakumar, & Baskaran, 2019; Espitia et al., 2014; Ruiz-Navajas et al., 2013). Role of plant extracts on the properties of packaging material including physical, mechanical, barrier, and functional properties will be addressed in this chapter.

11.2 Potential plant extract for packaging

The numerous functionalities and status of herbal extracts for use in foods have recently created great interest in food applications by mixing them into dietary biopolymer-based packaging materials (Wang, Marcone, Barbut, & Lim, 2012b).

Nowadays, significant attention is being paid to emerging innovative ideas of smart/intelligent, active, and eco-friendly food packaging systems. The packaging has been given new functionalities, mainly resulting from the recent consumer's desire for organic and clean-label- high-quality products. The most prevalent approach used to create active packaging is the integration of the active agent into the packaging matrix. The active agents would be classified as direct additives since the functional agent is predestinated to contribute to the profile of the ingredients of the food product. The successful packaging techniques often offer remedial approaches for food safety and preservations, without food additives being involved. For instance, the covalent bond between the active agent and the packaging material enables it to provide the activity without migrating to the structure of the food. Antimicrobial active packaging that belongs to the active packaging family is basically a packaging device that includes antimicrobial agents (AAs). Traditional direct application of AAs on food surfaces (e.g., dipping, spraying or pulverization) may lead to changes in taste due to excessive amounts of active components. Early evaporation and inactivation or denaturation of active agents by food additives, as well as rapid migration into the food mass, can take place using direct application techniques. Edible films give environmental compatibility along with improved food quality and shelf life and reduce potential loss of volatile flavors and aromas (Lim, Jang, & Song, 2010).

Currently, the tendency to decrease the use of synthetic additives in packaging has focused on replacing them with natural antioxidants, in particular tocopherol, plant extracts and herbal essential oils such as rosemary, oregano, and tea, which are safer and, in most cases, support multiple health benefits. Special consideration has been given to active packages with antioxidant properties because they are one of the most promising substitutes to traditional packaging where antioxidants are incorporated into or coated on food packaging materials to prevent oxidation of the product, which is one of the main causes of food spoilage (López-de-Dicastillo, Gómez-Estaca, Catalá, Gavara, & Hernández-Muñoz, 2012).

Grape skin is a by-product of the juicing operation as well as abundant in phenolic compounds including non-flavonoids and flavonoids. Glucosides of cyanidin, malvidin, delphinidin, peonidin, petunidin, and pelargonidin are the most plentiful anthocyanin in grape skin. In fact, the most antioxidant activity is observed in the skin of the grape. Hence, it is potentially valuable to incorporate grape skin extracts into polymers to improve food packaging (Alexandre et al., 2016; Oladzadabbasabadi, Karazhiyan, & Keyhani, 2017).

Plant-based products are superlative substitutes to chemical preservatives, and their use in food meets consumer demands for minimally processed natural products while providing some additional benefits for both food and consumers. Extract of the grape seed comprises fairly high amounts of flavonoids, including monomeric flavanols, trimeric, dimeric, polymeric, and phenolic acids. *Zataria multiflora* essential oil (ZEO) has large amounts of oxygenated phenolic monoterpenes and in in-vitro revealed antifungal, antioxidant, and antimicrobial activity (Moradi et al., 2012).

One of the superlative consumed drinks is tea due to its bioactive compounds related to various health benefits. In most cases, tea extracts are potent antioxidants. Epigallocatechin is 30 times greater than vitamin E and 20 times more active than vitamin C in some studies. Research studies demonstrated that both green tea and black tea extracts (BTE) had the powerful antimicrobial and antioxidant ability (Peng, Wu, & Li, 2013). Phenolic compounds are natural components which are typically extracted from vegetables and fruit. Phenolic ingredients are mostly combined into starch-based films to enhance active packaging due to strong antioxidant and microbial activities. The phenolic-rich starch-based films could be used to prolonging the food shelf life (Qin et al., 2019). The come about proposed that the Nano-composite films containing grapefruit seed extract (GSE) or thymol may amplify the shelf life of food (Lim et al., 2010). Antioxidant active films were successfully developed using a casting method based on an ethylene-vinyl alcohol copolymer and natural antioxidants. Thermal analysis showed that the materials had degradation of the crystallinity structure and about 4% of the remaining solvent that led to a loss of the barrier properties compared with extrusion materials (López-de-Dicastillo et al., 2012). Ma, Ren, and Wang (2017) carried out the study on the formulation of a pH-sensing film based on Tara gum that combines cellulose with grape skin extracts. They found that in the pH range of 1−11 the visual color changed from red to slightly green and the resulting film reacted well to the milk spoiling process. The film may be used as a clear pH- label, and the film's color change offers a simple path to tracking packaged food freshness. Moradi et al. (2012) reported that the addition of grape seed extract and *Z. multiflora* Boiss essential oil into the chitosan film improved surface wettability, total phenol activity and antioxidant activity. The films integrated by neat chitosan and ZEO had a light yellowish color, while the films incorporated by GSE + ZEO were gray. The findings also showed that GSE formulated chitosan film can be used as an active film due to its excellent percentage of % SI and antioxidant properties in medium moisture products, such as muscle food. Comprehensive reviews on inclusion essential oils and nanoparticles into meat and meat products active packaging mechanisms have been published by (Kargozari & Hamedi, 2019). The effects on the physical, structural and antioxidant properties of chitosan films of 0.5%, 1% and 2% green tea extracts (GTE) and BTE were studied (Peng et al., 2013). Results showed that the incorporation of tea extracts considerably reduced the water vapor permeability and improved film antioxidant capability.

In all food simulants ethanol, the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capability of GTE films was stronger than that of BTE films. The equilibration time in different simulants of foods decreased with increased concentration of ethanol. This study found that active chitosan film could be obtained by incorporating tea extracts, which could provide new formulation options for the development of active antioxidant packaging. Active and intelligent packaging films have been successfully developed by incorporating various quantities of *Lycium ruthenicum* anthocyanins (LRA) into the starch matrix (Qin et al., 2019). The incorporation of LRA has significantly enhanced the moisture content, WVP and mechanical strength of starch film owing to the hydrogen bonds formed between starch and LRA. Besides, the addition of LRA greatly improved the light barrier, antioxidant, and pH-sensitive properties due to anthocyanin functionalities. In future, starch-LRA films, besides that they can be used as active packaging films to increase the shelf life of foods. Also, they will be able to use them as smart packaging films to monitor food freshness in real-time. The results of the xyloglucan film from *Tamarindus* revealed that the film containing 4.5% xyloglucan and 1.5% glycerol was considered appropriate for use as a wrapping film in cut-up 'Sunrise Solo' papayas. They displayed a higher mass loss to the PVC film in their usage and were statistically equivalent to the production of ethylene and carbon dioxide. Despite these findings, the characterization and usage data indicated that xyloglucan from *Tamarindus indica* has acceptable properties about food and packaging (Santos et al., 2019). Cross-linked polymers prepared from sodium alginate/pectin (P) with tartaric acid and citric acid by Singh, Baisthakur, and Yemul (2020). Pectin and sodium alginate were extracted from waste pineapple rind and seaweed, respectively. The crosslinked films have been characterized using different analytical methods. Through the edibility test by mice feeding method, they proved that these crosslinked polymers are edible. They claimed that these newly polymeric films as a green food wrapping material can be useful to enhance the shelf life of food such as chocolate and Indian vegetable puff. The waste pineapple shell has successfully been turned into an edible packaging film with value-added application in food packaging. Poly (ethylene terephthalate)/ polypropylene (PET/PP) films containing extract of olive leaves (OLE) were produced in batch (BM) and semi-continuous modes using supercritical solvent impregnation by Cejudo Bastante et al. (2019). The research focused on the effect on the properties of the impregnated films from pressure, temperature, CO_2 flow and OLE. Thermal examination of unimpregnated samples showed a decline in the crystallinity of the treated PP layer at 35°C and a rise in the Tg of PET treated at 55°C due to CO_2 sorption. Conditions of 400 bar and 35°C in BM overall were optimal for the development of highly antioxidant films with slight structural changes. Agar-based bionanocomposite films with ZnO nanoparticles as an active material for shelf life development of green grape packaging were investigated by Kumar, Boro, Ray, Mukherjee, and Dutta (2019). They have synthesized zinc oxide nanoparticles (ZnO NPs) using Mimusops elengi fruit extract as a new resource. Incorporation of ZnO NPs in composite films decreased tensile strength and transparency, whereas enhanced thermal stability, elongation, and film thickness. The films were utilized for packaging of green grape and the forms of the fruits were controlled throughout storage. Grapes packaged in composite films with 4% (w/w) ZnO NPs displayed fresh appearance up to 21 days during storage. The findings demonstrated the ability of the fabricated agar-ZnO nanocomposite film as useful packaging materials to improve the shelf life of fresh fruit, such as green grapes, after harvest. Wang, Marcone, Barbut, and Lim (2012a) demonstrated anthocyanin-rich red raspberry (*Rubusstrigosus*) extract (ARR) can be used to enhance the material properties of soy protein isolate (SPI) films and probably other protein-based films. ARRE resulted in an SPI film having remarkably improved tensile strength ($P < .05$) and % elongation at break ($P < .05$), also increased water swelling ratio ($P < .05$) and in vitro pepsin digestibility ($P < .05$). Besides, ARRE increased darkness, redness, and yellowness film appearance than the control film. The produced films also exhibited greatly reduced water solubility and water vapor permeability. Wang et al. (2012b) have reviewed. This review showed that current evidence that with the incorporation of plant extracts, various physical characteristics of edible biopolymer materials can be modified. Moreover, bioactive ingredients (antioxidant or antimicrobial activities) of plant extract in these materials have also been identified and considered. The interaction between plant extract and biopolymers has a well-recognized. Plant extracts can improve the properties of dietary polymers in food packaging. In overall, it could be claimed that the application of natural plant extracts would be a high potential non-toxic and natural compound to make dietary biopolymer-based materials with different usage.

Song, Shin, and Song (2012) have evaluated the physical properties of a composite film prepared from barley bran protein and gelatin (BBG). With an increase of barley bran protein content, Tensile strength (TS) and elongation at break (E) values of the BBG film were reduced. E values decreased by increasing gelatin content, while TS increased. Also, they investigated a BBG film containing GSE to inhibit the growth of pathogenic bacteria. Populations of *Escherichia coli* O157: H7 and *Listeria monocytogenes* inoculated on salmon packaged decreased after 15 days of storage. Besides, decrease the peroxide value and the thiobarbituric acid value was observed in packing salmon with the BBG films containing GSE. Because of film-forming ability and low cost of BBP, it can be used as an effective edible film source for packing of salmon during storage. In another study, chitosan-based composite films with different amounts of GSE were fabricated via casting method. In addition, the packaging of bread samples containing composite GFSE chitosan-based films prevented fungal growth in comparison with control samples. Therefore, GFSE composite chitosan-based films have the potential to be an important alternative in food technology (Tan, Lim, Tay, Lee, & Thian, 2015).

11.2.1 Antimicrobial activity aids

Nowadays, attention to the production of high-quality safe food and excellent extending shelf life has led to increasing research and efforts to develop new bio-based packaging materials and antimicrobial packaging (Kanmani & Rhim, 2014a; Marvizadeh, Oladzadabbasabadi, Mohammadi Nafchi, & Jokar, 2017; Sganzerla et al., 2020; Treviño-Garza, Yañez-Echeverría, García, Mora-Zúñiga, & Arévalo-Niño, 2020; Wang, Lim, Tong, & Thian, 2019). In total, antimicrobial packaging is accomplished by merged antimicrobial agents directly into packaging films, coating antimicrobial packaging films, and packaging materials made from polymers with natural antimicrobial properties (Wang, Lim, et al., 2019).

In one hand, it is of great importance to use biodegradable nanocomposite films in active packaging because they can provide a controlled release of antimicrobial compounds (Sani, Ehsani, & Hashemi, 2017).

On the other hand, to produce active packaging films, compounds including bacteriocins, enzymes, spice extracts or essential oils, plant seed extract, organic acids, fatty acids, nano-sized metal, and metallic oxides have been used as efficient antimicrobials. Among them, because of their potential antimicrobial activity and adaptability with biopolymer matrices, natural antimicrobials such as essential oils, spice extracts, and fruit seed extracts are extensively used particularly in the food packaging field (Kanmani & Rhim, 2014a). Current knowledge shows that several plant extracts may significantly reduce or inhibit the growth of pathogenic and spoilage microorganisms. Most of the natural options for synthetic food preservatives studied in recent research are raw or pure plant extracts, that is, essential oils or pure ingredients that have become the center of interest for on-site use in food products (Bouarab Chibane, Degraeve, Ferhout, Bouajila, & Oulahal, 2019). Further, delay and inhibition of bacterial growth on food products play an important role in the preparation of active packaging because the attack on causative bacteria and food poisoning is the main cause of food deterioration among inherent and external factors (Nguyen et al., 2020). Therefore, microbial growth regulation in food products has always been the main concern for the various stakeholders in the agri-food industry. Then, a twofold challenge must be taken into consideration: maintaining both food health and reducing food waste. The use of natural antimicrobials to preserve food is a concept pursued by consumers and food producers. Due to the increasing requirement for minimally processed products, especially those containing natural additives, their use is expected to increase progressively in future. Despite significant efforts to develop manufacturing methods, distribution, hygiene practices and public awareness, spoilage and food-borne pathogenic microorganisms still result in tremendous unacceptable human costs and economic losses. Owing to Increased consumption of minimally processed, fresh and ready-to-eat food has resulted in new ecological pathways for microbial growth. Consumers demand "healthier" and more environmentally sustainable food production processes to ensure the microbial protection of their products, which encourage the creation of creative bio preservation technologies focused on the use of natural antimicrobial agents rather than synthetic preservatives (Bouarab Chibane et al., 2019). Thus the application of plant extracts in edible coating films as natural antimicrobials may fulfill the rising consumer requirement for safe, convenient, and fresh food (Ma, Ren, Gu, & Wang, 2017; Nguyen et al., 2020).

This research was conducted to determine the effectiveness of whey protein isolate and cellulose nanofiber nanocomposite films titanium dioxide and rosemary essential oil in maintaining the microbial and sensory consistency of lamb meat during storage at $4 \pm 1°C$. The best concentration of each compound to be applied to the film was initially calculated by methods of micro-dilution and disk diffusion. During 15 days of storage, the microbial and sensory properties of lamb meat were tested in two groups (control and treatment). For the sensory analysis, microbial analysis, and a hedonic scale of nine points were applied. Tests showed that the application of nanocomposite films greatly decreased the treatment group's bacterial counts. Higher inhibition effects on Gram-positive bacteria were observed compared to Gram-negative bacteria. The microbial and sensory tests also indicated that the nanocomposite films prolonged the shelf-life of treated meat considerably (15 days) comparison to the control meat (6 days). Edible nanocomposite films have been efficient in protecting the microbial and sensory qualities of lamb meat; thus, this application is especially suggested in red meat by (Sani et al., 2017).

Chen et al. (2020) developed antimicrobial packaging film based on cellulose nanofiber and a pH indicator with incorporation of oregano essential oil as an antimicrobial agent and anthocyanins which extracted from purple sweet potato as a natural dye. The film showed excellent colorimetric efficiency to pH change and superior antimicrobial activity and the *E. coli* and *L. monocytogenes* inhibition levels exceeded 99.99%. With the addition of anthocyanins and essential oregano oil, the film's crystallinity index decreased. Moreover, the pH indicator developed, and the antimicrobial film activity could suggest food quality changes during storage and efficiently extend food shelf life.

Another study was conducted by Dong, He, Xiao, and Li (2020) to investigate the antimicrobial activity and sustained release kinetics of cinnamyl aldehyde and carvacrol in temperature-sensitive polyurethane (TSPU) film. For the potential use of food packaging, TSPU films combined with carvacrol and cinnamyl aldehyde have been prepared. Results showed that at relatively low addition ratio cinnamyl aldehyde and carvacrol had beneficial antimicrobial properties. The kinetic equation of first order may be used to describe its diffusion and the process of sustained release. TSPU films could greatly increase the shelf life of moon cakes in the Cantonese style by effectively inhibiting microbial growth and decreasing lipid oxidation compared with widely used food packaging for polyethylene. In a recent article by Nguyen et al. (2020), the development of physiochemical properties and antimicrobial activities of chitosan edible film with *Sonneratia caseolaris* (L.) Engl. leaf extract (SCELE) were investigated. Vietnamese banana fruit was picked to preserve food and the presence of coated bananas with and without composite films based on chitosan was evaluated. The findings suggested that the presence of SCELE could increase the antimicrobial function, water vapor barriers, while a substantial reduction in light transmittance was observed. Bananas coated with a chitosan matrix-based composite film and SCELE had a longer life than the control sample and those covered with pure chitosan film, suggesting that the incorporation of SCELE into a chitosan matrix brings potential application for active edible food packaging. The growth of tested Gram-negative bacteria was strongly inhibited, and antibacterial activity was enhanced by using chitosan film incorporated with SCELE after 12 h exposure. During 12 h exposure to *Pseudomonas aeruginosa*, the greatest antibacterial activity of chitosan film with incorporated 1% and 3% SCELE was found. It can be shown that the inhibitory efficacy of Gram-negative bacteria blend films depends on both SCELE content and exposure time. Active Polylactide Films (PLA) containing *Allium ursinum* extract L. (AU), also known as wild garlic, was successfully prepared using the electrospinning technology at 10% wt. by Radusin et al. (2019). Electrospinning of the AU-containing PLA solutions produced beaded-like morphology fibers in the range 1–2 μm, indicating that the AU extract was primarily encapsulated in certain fiber regions. Cross-sections of the film showed that the AU extract was inserted as micro-sized droplets into the PLA matrix. The thermal properties showed that the addition of the AU extract plasticized the PLA matrix and also lowered its degree of crystallinity as it interfered with the ordering of the PLA chains by impeding their folding into the crystalline lattice. Analysis of thermal stability suggested that the natural extract contributed positively to a gap in the biopolymer's thermal degradation and was thermally stable when encapsulated in the PLA film. Significant antimicrobial activity against foodborne bacteria has been achieved by electrospun PLA film containing the natural extract. The free AU extract performed very well against *E. Coli* and demonstrated a 100% reduction in viable cells compared to control. Its effectiveness against *S. aureus* was also notable, that is, a reduction of 53% after 24 h.

The study of antimicrobial, physicomechanical, and barrier properties on linseed mucilage films with addition of *Hamamelis. virginiana* extract demonstrated that increased interest in providing excellent quality and shelf-life for safe food has led to increased efforts to expand new bio-based packaging materials. The goal of this study was to develop and characterize linseed mucilage (LM)-based films at concentrations of 2.0%, 2.5%, and 3.0%, as well as to improve antimicrobial films (AFs) that contain *H. virginiana* (Hv) extract. Based on its mechanical properties, water vapor permeability and moisture sensitivity, the films with the greatest concentration of LM were selected as the best formulating. Minimum inhibitory concentrations were 1.18 mg/mL for *L. monocytogenes* and 2.37 mg/mL for *S. typhi, S. aureus, and E. coli*. Finally, by incorporating 2.37 mg/mL of Hv extract with a base of 3.0% LM, AFs were enhanced and improved antioxidant, antimicrobial and moisture activity. It also reduced water vapor permeability and tensile strength. These outcomes suggest that studied films have adequate properties for packaging material (Treviño-Garza et al., 2020).

A list of recent research conducted in this area is presented in Table 11.1.

11.2.2 Antioxidant activity aids

Antioxidant packaging is a great type of active packaging and a very promising food preservation technique to extend the shelf life of food products. As oxidation is one of the major reasons for food spoilage, insertion of antioxidants into packaging film as an antioxidant packaging has become very popular (Wu et al., 2013). The main categories of active packaging are antioxidant and antibacterial packaging which have the potential to extend the shelf life of food products and enhance the sensory properties (Bonilla & Sobral, 2016; Ma, Ren, Gu, et al., 2017). Synthetic antioxidants are commonly used for inhibiting the oxidation of food products in the food industry. Examples of common synthetic antioxidants used in food commodities are butylated hydroxyanisole (BHA) and butylated hydroxytoluene. However, some artificial additives could change the food flavors and give a different taste. Moreover, consumers today tend to not use synthetic chemicals in their products because of their concern about the harmful effects on human health (Adilah et al., 2018). The use of natural antioxidants and antimicrobials components in the protection of food is an alternative to chemical products (Bonilla & Sobral, 2016; Pastor, Sánchez-González, Chiralt, Cháfer, & González-Martínez, 2013). Owing to their high concentrations of bioactive ingredients with antioxidant and/or antimicrobial activity, edible plants, especially those rich in secondary metabolites (e.g., essential oils, polyphenols) are of increasing interest. The addition of natural extracts into

Table 11.1 Antimicrobial activity of plant extracts in food packaging.

Plant-derived	Packaging material	Packaged product	process	Antimicrobial effect	References
Grape seed extract	Pee-starch films	Pork loin	Casting	Prevent growth of *B.thermosphacta* and of undesirable pathogens in meat, enhancing quality and shelf life of food	Corrales, Han, and Tauscher (2009)
GSE or thymol	Gelidium corneum/nano-clay composite	–	Casting	Growth prevention of *Listeria monocytogenes and Escherichia coli*, prolong the shelf life	Lim et al. (2010)
Wine grape pomace water extract	Low-methoxyl pectin, sodium alginate, Ticafilm	Colorful wraps for different food	Casting	Demonstrated antibacterial activity against *Listeria innocua* and *E. coli*,	Deng and Zhao (2011)
Thyme and oregano essential oils	–	Lamb meat	–	Decrease microbial populations and lipid oxidation, extended the shelf of meat during storage	Karabagias et al. (2011)
Grapefruit seed extract	Rapeseed protein–gelatin film	Strawberry	Casting	Growth inhibition of *L. monocytogenes* and *E. coli*, prolong the shelf life of fruit	Jang, Shin, and Song (2011)
Grapefruit seed extract	Bran protein–gelatin composite film	Salmon	Casting	Reduced population of *L. monocytogenes* and *E. coli*, grapefruit seed extract (GSE) showed antimicrobial activity, impressive preserving against oxidation of lipid	Song et al. (2012)
Quillaja saponaria Mol. extracts	Milk proteins (calcium caseinate and whey protein isolate)	Strawberry	Coating	Prevent the growth of Botrytis cinerea, increased the shelf life of fruit	Zúñiga et al. (2012)
Grapefruit seed extract	Red algae	Cheese, bacon	Casting	Reduced the population of pathogenic bacteria such as *L. monocytogenes* and *E. coli*, enhanced the shelf life of food	Shin, Song, Seo, and Song (2012)
Thymus. piperella and *Thymus. moroderi* EOs	Chitosan films	Food product	Casting	Great antibacterial activity, inhibit growth of Gram-negative and Gram-positive bacteria, extended the shelf of life	Ruiz-Navajas et al. (2013)

(*Continued*)

Table 11.1 Antimicrobial activity of plant extracts in food packaging. ***Continued***

Plant-derived	Packaging material	Packaged product	process	Antimicrobial effect	References
Cinnamon EOs	Corn starch	Bread	Encapsulation	Reduced the growth of yeast and mold, decrease microbial growth, extended the shelf life	Lotfinia, Javanmard Dakheli, and Mohammadi Nafchi (2013)
Green tea extract	Agar/Agar-fish gelatin	–	Casting	Demonstrated antimicrobial activity against different microorganisms	Giménez, López de Lacey, Pérez-Santín, López-Caballero, and Montero (2013)
Grapefruit seed extract	Agar-based film	Food product	Casting	Showed antimicrobial activity against *L. monocytogenes*, *E. coli* and *Bacillus cereus*, prolonging the shelf life of food	Kanmani and Rhim (2014a)
Sweet basil hydroalcoholic extract	Pullulan film	Jonagored apples	Coating	Prevented growth of Gram-negative bacteria, showed great antimicrobial activity, antifungal properties against R. arrhizus, extended the shelf of life	Synowiec et al. (2014)
GSE	Carrageenan-based film	Food packaging	Casting	Excellent antimicrobial activity against Gram-positive and Gram-negative pathogens, enhanced the shelf life	Kanmani and Rhim (2014b)
Satureja hortensis L. water extract	Pullulan films	Pepper and apple	Casting	Growth inhibition of Gram-negative and Gram-positive bacteria, extended the shelf life of food during storage	Kraśniewska et al. (2014)
Betel leaf extract	Sago starch film	–	Casting	Improve antimicrobial activity against Gram-negative and Gram-positive bacteria except *Psuedomonas aeruginosa*	Nouri & Mohammadi Nafchi (2014)
Apple skin extract Thyme essential oil	Acaí-based film and pectin	–	Casting	Good antimicrobial activity against *L. monocytogenes*	Espitia et al. (2014)
Cinnamon essential oil	Chitosan nanoparticles	Meat	Ionic gelification	Increased *Pseudomonas spp.*, *Enterobacteriaceae* and LAB Counts, remarkably reduced the microbial growth, improve the shelf life of food during storage time	Hu et al. (2015)

Allium spp. extract	Polylactic acid	Ready-to-eat salads	Extrusion	Decrease the growth of *Fusarium spp., Alternaria spp., Peniciliumdigitatum and Zygosaccharomicesbailii, Staphylococcus aureus*	Llana-Ruiz-Cabello et al. (2015)
Oregano oil	Red pepper seed meal protein-gelatin-composite	Fatty tuna meat	Casting	Decrease the populations of *S. Typhimurium* and *L. monocytogenes*, extended the shelf life	Lee et al. (2016)
Satureja thymbra (L.) extracts	carboxymethyl-cellulose	Marine cultured gilthead seabream fillets	Casting	Lower TVC, great antimicrobial effects, enhanced the shelf life	Choulitoudi et al. (2016)
Murta leaf extract	LDPE	–	Casting	Decreased growth of *Listeria (L.) innocua*, shelf-life extension	Hauser et al. (2016)
Murta fruit extract	Methylcellulose	–	Casting	Remarkably decrease the growth of bacteria	López de Dicastillo, Bustos, Guarda, and Galotto (2016)
Cinnamon extract, guarana extract, rosemary extract and boldo-do-chile extract	Gelatin-chitosan	–	Casting	Strong inhibit growth against *E. coli* and S. *aureus*, prolonging shelf life	Bonilla and Sobral (2016)
Oregano extract	–	Sheep burger	–	TVC and LAB increased remarkably	Fernandes, Trindade, Lorenzo, Munekata, and de Melo (2016)
Moringa plant extracts	Carboxyl methylcellulose	Avocado	Coating	Great antimicrobial, preventing postharvest diseases, enhanced the shelf life of fruit	Tesfay, Magwaza, Mbili, and Mditshwa (2017)
Green tea extract	Chitosan film	Raw chicken meat	Casting	Prevent the growth of Gram-negative and Gram-positive bacteria, improved shelf life of food	Mujeeb Rahman, Abdul Mujeeb, and Muraleedharan (2017)
Grape seed extract and carvacrol	Chitosan film	Salmon meet	Casting	Lower bacterial counts observed, improvement of shelf life of food	Alves et al. (2018)
Grape seed extract	Chitosan film	Chicken breast fillets	Casting	Prevent growth of *E. coli, L. monocytogenes, S. aureus* and *Pseudomonas aeruginosa*, increase the shelf life of food	Sogut and Seydim (2018)

(*Continued*)

Table 11.1 Antimicrobial activity of plant extracts in food packaging. ***Continued***

Plant-derived	Packaging material	Packaged product	process	Antimicrobial effect	References
Apple peel polyphenol extract	Chitosan	–	Casting	Exhibited antimicrobial activity to control *E. coli, B. cereus, S. aureus and S. typhimurium*, extended the shelf life	Riaz et al. (2018)
Grapefruit seed extract	PLA/PBAT composite films	–	Casting	Antibacterial activity against *L. monocytogenes*, bacteriostatic activity against *E. coli*	Shankar and Rhim (2018)
Grapefruit seed extract	Poly (ε-caprolactone)/ chitosan	Salmon bread	Extrusion	Prevent the growth of *E. coli*, prolonging the shelf life of food	Wang, Yong, et al. (2019)
Supercritical CO2 hop extract	Chitosan	–	Casting	Showed antibacterial activity against foodborne pathogen *Bacillus subtilis*, enhance the shelf life	Bajić, Jalšovec, Travan, Novak, and Likozar (2019)
Rosemary extract	EVA with ZnO/ Fe-MMT	–	–	Demonstrated antibacterial activity to control *E. Coli* and *Staphylococcus Ureus*, showed significant antimicrobial activity, prolonging the shelf life	Eskandarabadi et al. (2019)
Pomegranate peel	Starch	–	Casting	Strongly showed that prevented growth of *S.aureus* and *salmonella*, increased inhibition zone	Ali et al. (2019)
Cashew nut testa extract	Cellulose	–	Interfacial self-assembly	Extend the shelf life antimicrobial activity toward the food pathogens *Escherichia* and *S. aureus*	Lee, Cui, Chai, Zhao, and Chen (2020)
Mangosteen rind powder	Chitosan	Soybean oil	Casting	Inhibit food spoilage and oxidation, exhibited great antimicrobial ability against Gram-positive bacteria than Gram-negative bacteria, prolonging the shelf life	Zhang, Liu, et al. (2020)
Chinese chives root	Chitosan	–	Casting	Preventing growth of Gram-positive and Gram-negative bacteria	Riaz et al. (2020)
Blood orange peel pectin	Fish gelatin	Cheese	Casting	Showed the antibacterial activity against four Gram-negative and Gram-positive bacteria	Jridi et al. (2020)

Red pitaya (*Hylocereuspolyrhizus*) peel extract	Starch/PVA	–	Casting	Improved antimicrobial activity against *S. aureus, E. coli, Salmonella, L. monocytogenes*, enhance the shelf life	Qin, Liu, Zhang, and Liu (2020)
Pectin extracted from pineapple	Sodium alginate and citric or tartaric acid	Chocolate, Indian vegetable puff	Casting	Inhibited the growth of bacteria, improve the shelf life	Singh et al. (2020)
Rheum ribes L. ethanol extract	Methylcellulose	Alternative biodegradable food packaging.	Casting	Preventing the growth of *B. cereus, E. coli, S. aureus, L. monocytogenes, Salmonella Typhimurium, Klebsiella pneumoniae*, and *Proteus vulgaris*	Kalkan, Otağ, and Engin (2020)
Cinnamon essential oil/ TiO2-N	Sago starch film	Fresh pistachio	Casting	Great antimicrobial activity against *E. coli, S. aureus* and *Salmonella typhimurium*	Arezoo, Mohammadreza, Maryam, and Abdorreza (2020)
Thyme essential oil	Orientated polypropylene or LDPE		Immersion	Better antimicrobial activity against Gram-positive bacteria	Mousavian, Mohammadi Nafchi, Nouri, and Abedinia (2020)
Mentha piperita Essential Oil	Cassava Starch	Food and non-food packaging	Solution intercalation	Antimicrobial activity against *S. aureus* and *E.coli*	Marvizadeh, Tajik, Moosavian, Oladzadabbasabadi, and Mohammadi Nafchi (2020)
Cinnamon EOs/TiO_2-NPs	Sago starch	Fresh pistachio	Casting	Decrease aflatoxins, limited the growth of *A. flavus*, extended the shelf life	Esfahani, Ehsani, Mizani, and Mohammadi Nafchi (2020)
Nigella sativa L. seeds	Sago starch	–	Casting	Higher antimicrobial properties against the Gram-negative and Gram-positive bacteria	Ekramian, Abbaspour, Roudi, Amjad, and Nafchi (2020)
Olive leaf extract	–	Gluten-free bread	Encapsulation	Enhanced antifungal properties, extended the shelf life	Moghaddam, Jalali, Nafchi, and Nouri (2020)

gelatin-based films can enhance the functional and physical properties of the film (Bonilla & Sobral, 2016). The integration of antioxidants into the packaging film is also used as oxidation is the main issue that affects the quality of the food. Antioxidants decrease the amount of chemical additives used in food because they have loaded on films could transmittance from the packaging to the food and inhibit direct contact with food. The current research based on natural active compounds rather than synthetic compounds due to consumer health concerns (Ma, Ren, Gu, et al., 2017; Maryam Adilah, Jamilah, & Nur Hanani, 2018). These natural compounds include those in green-tea extract (Siripatrawan & Harte, 2010; Wu et al., 2013), grape seed extract (Moradi et al., 2012), black soybean seed coat extract (Wang, Yong, et al., 2019; Yuan et al., 2020), α-tocopherol (Marcos et al., 2014), pomegranate peel (Ali et al., 2019; Moghadam, Salami, Mohammadian, Khodadadi, & Emam-Djomeh, 2020), thyme extract (Talón et al., 2017), curcumin (Ma, Ren, Gu, et al., 2017), banana peels extract (Zhang, Li, & Jiang, 2019) and essential oils (Ruiz-Navajas et al., 2013). There has been an increasing interest in the use of natural additives with antioxidant properties derived from plant extracts as alternatives due to reducing the use of chemical additives in the food industry. Nevertheless, the palatability of food products can be adversely affected in most cases by the direct introduction of natural compounds. The addition of these naturally occurring antioxidants into films seems to be a safe method for the gradual release of these additives into the food over its shelf life (da Rosa, Vanga, Gariepy, & Raghavan, 2020). Biodegradable films with natural antioxidant seemed to be an interesting way to preserve the quality of food and provide extra preservation for oxidative agents as compounds migrated to the food material, thereafter, promoting longer shelf life. Compared to synthetic antioxidants which could have possible toxicity, natural antioxidants such as an extract from plants were recommended. Typically, most fruits' pericarps, skins or peels are not consumed and disposed of as residue. Nevertheless, phenolic acids usually occurring in the outer sections of plants such as shells, skins, and pericarps have been identified (Nabilah, Wan Zunairah, Nor Afizah, & Nur Hanani, 2019). Researchers have recently focused on the insertion of natural bioactive compounds like phenolic compounds, α-tocopherol and essential oils into packaging materials to the produce active edible films to improve the shelf-life of food products and preserve their quality and safety without the use of synthetic additives (Moghadam et al., 2020). A variety of technological approaches may be used for active antioxidant packaging. Most of them contain either of the co-extrusion of the antioxidant together with the film-forming plastic substance or direct combining of an antioxidant agent with the plastic substances. Researchers have been outlined the promising findings of a modern active antioxidant packaging method (Camo, Lorés, Djenane, Beltrán, & Roncalés, 2011).

11.2.2.1 Polysaccharide-based film

Enhancement of active packaging chitosan-based films including mangosteen rind powder was done by Zhang, Liu, et al. (2020). Mangosteen (*Garcinia mangostana* L.) rind due to the presence of high polyphenols content and potent antioxidant and antibacterial ability has known as a traditional medicine in Southeast Asia. The goal of this study was developed chitosan (CS) active packaging film with incorporated mangosteen rind powder (MRP). Fourier transform infrared spectroscopy showed that the MRP polyphenols could interact with CS growing intermolecular hydrogen bonds. The addition of MRP greatly improved the CS film's thickness, strength and UV-visible light barrier, antioxidant, and antibacterial properties. In addition, CS-MRP film packaging effectively prevented the increase of soybean oil's peroxide value and thiobarbituric acid reactive substances during storage. The findings demonstrate that films CS-MRP could be used to improve the oxidative stability of soy oil in the food industry as active packaging. In an evaluation, the effect of guarana, cinnamon, rosemary and boldo-do-chile ethanolic extracts of gelatin: chitosan on the optical, microstructural, barrier and mechanical properties of the films were investigated as well as the antimicrobial and antioxidant activity, Bonilla and Sobral (2016) found that the microstructural and FTIR studies verified both polymers were homogeneously blended in the film matrix. Increments in the proportion of chitosan improved the elasticity of the films and produced a decrease in the permeability of water vapor, which was not substantially decreased with the incorporation of the extracts. In the TEAC test, the blends films revealed good antioxidant properties and a great inhibition of growth against *E. Coli*, and *S. aureus*, suggested that these films based on mixtures of gelatin and chitosan and ethanol extract additives Can be an option for food applications as an active packaging material. Zhang et al. (2019) was developed the antioxidant chitosan (CS)-banana peels extract (BPE) composite film. The different content of BPE (4%, 8% and 12%) was added to the CS film not only as the antioxidant but also as the cross-linking. The CS-BPE composite film displayed great antioxidant activity in food packing. The optimum concentration of CSBPE coating treatment was applied to apple fruit, and the results indicated that CS-BPE coating was more capable of enhancing apple fruit post-harvest quality than CS coating. Wang, Dong, Men, Tong, and Zhou (2013) developed chitosan active films with incorporated tea polyphenols. Fourier transform infrared spectrometry has been used to evaluate the potential interactions in the films between chitosan and tea polyphenols. The results of the tests showed that the incorporation of tea polyphenols caused interactions between tea polyphenols and chitosan and produced darker film appearances. The films showed increased water solubility after the introduction of tea polyphenols and reduced water vapor permeability. In the meantime, the incorporation of tea polyphenols has increased the total phenolic content. But with time, the chitosan film's antioxidant activity integrated tea polyphenols declined. In another study, food packaging films were enhanced based on chitosan (CS) containing anthocyanin-rich purple eggplant extract (PEE) or black eggplant extract (BEE). The amount of anthocyanin in PEE and BEE were 93.10 and 173.17 mg/g, respectively. The compositions of anthocyanin in PEE and BEE were completely different. BEE and PEE increased the thickness, blueness, UV−vis light barrier and mechanical properties of CS film. The antioxidant ability of CS film was greatly improved by adding PEE and BEE (Yong, Wang, Zhang, et al., 2019). Jamróz, Kulawik, Guzik, and Duda (2019) were developed Antioxidant and pH-sensitive chitosan-based films by incorporating various concentrations of black soybean seed coat extract (BSSCE). The addition of BSSCE could significantly alter the optical, barrier and mechanical properties of chitosan film. In particular, the chitosan-BSSCE film showed better water vapor and UV-vis light barrier properties and stronger mechanical strength than the chitosan film. Moreover, chitosan films displayed higher moisture content and transparency than chitosan-BSSCE films. Among all the films examined, the best performance was the chitosan-BSSCE film containing 15 wt.% of BSSCE on chitosan basis. Results indicated that chitosan-BSSCE films could be used as promising food packaging materials for the antioxidant and visible pH sensing. Talón et al. (2017) examined the antioxidant activity of various chitosan- and starch-based polymer matrices, incorporating a polyphenol-rich thyme extract (TE). TE had significant antioxidant activity on the films. When mixed with chitosan, enhancing the tensile behavior of films due to the polyphenols interacted with the polymer chains, acting as crosslinkers. The results suggested it could be used these antioxidant films for extending the shelf life of the products sensitive to oxidative.

Antioxidant activity and physical properties of chitosan film containing GTE were studied by Siripatrawan and Harte (2010). The aim of this study was developed prepared active film from chitosan with incorporated aqueous GTE. The results showed that addition of GTE into chitosan films enhanced water vapor barrier and mechanical properties and improved polyphenolic content and antioxidant activity of the films. Changes in the chitosan films FTIR spectra were observed when GTE was added, indicating that interactions between chitosan and GTE polyphenols occurred.

Riaz et al. (2018) developed a novel functional film with the incorporation of apple peel polyphenols (APP) into chitosan (CS). The results demonstrated that the addition of APP into CS notably enhanced the film physical properties by increasing its thickness, opacity, solubility, density, and swelling ratio while moisture content and water vapor permeability were reduced. Thermal stability was reduced in the prepared films whereas antimicrobial and antioxidant activities of the CS-based APP film were considerably increased. CS-APP film with 0.50% APP concentration performed good mechanical and antimicrobial properties that pointed out it can be enhanced as bio-composite food packaging material.

Akhtar et al. (2012) prepared HPMC films including a natural red color compound (NRC) at different concentrations. This research showed that natural plant extracts could be used with additional benefits for the functionalization of edible films. These films supply unique fruit taste, color and antioxidant ability which would greatly improve their potential applications in both food and non-food industries. Infrared spectroscopy study has verified miscibility of HPMC and NRC in composite films. Absorption bands in the FTIR spectra indicated interactions between components by hydrogen bonding. Increased peak area in this region was directly adequate to the concentration of the NRC making films more hydrophilic. During the film preparation steps NRC antioxidant capacity was stable. When NRC increased, color of edible films became darker and redder, while a rising effect of light exposure on color stability was observed. Results indicated that because of their color, plasticizing properties, good antioxidant stability and the ability to protect HPMC from photo-degradation, NRC films have good potential for food applications.

Pastor et al. (2013) carried out a study on the antioxidant properties of chitosan and methylcellulose-based films incorporating with resveratrol. New developments in edible films focus on improving their versatility by adding active compounds, such as antimicrobials or antioxidants. Resveratrol is a natural antioxidant present in a different of plant species, such as grapes which could be used to reduce or inhibit lipid oxidation in food products, postpone the development of oxidation products, preserve nutritional quality which extends the shelf life of food products. The goal of this paper was the development and characterization with the incorporation of various amounts of resveratrol in two different polymeric composite films made with chitosan and methylcellulose. By the presence of resveratrol, oxygen and water vapor permeability tend to moderately reduce and barrier properties of the film were hardly improved. Composite films demonstrate antioxidant activity, which was adequate to the concentration of resveratrol in the film. None of the films showed antimicrobial activity against *Penicillium italicum* and *Botrytis cinerea*. Hence, the result suggested these films could be used in food packing that sensitive to oxidative processes to extend their shelf life.

11.2.2.2 Gelatin-based film

Preparation, properties, and antioxidant activity of an active film from silver carp (hypophthalmichthys molitrix) skin gelatin incorporated with GTE were investigated by Wu et al. (2013).

The results of this study have shown that the incorporation of GTE into gelatin films has improved overall phenolic content, increased DPPH radical activity and reduced power. The thermal stability of gelatin-GTE films has been enhanced and increased with a rising concentration of GTE. FTIR spectra showed that the interaction of protein-polyphenol in gelatin-GTE films was involved. For gelatin-GTE films, smooth and homogeneous surfaces and compact structures were observed. As a result, the addition of GTE to gelatin film enhanced the antioxidant activity and the properties were most likely directly affected by interactions of gelatin with GTE. Zamuz et al. (2018) demonstrated that the appropriate combination of chestnut extracts in various sections (bur, leaf, and hull) can be used as a replacement for commercial antioxidants since adding chestnut extracts to bovine meat patties prevented lipid oxidation and delayed metmyoglobin formation without major sensory properties alteration. In this research through the incorporating tea polyphenol (TP) into gelatin and sodium alginate, active edible films were prepared. By increase TP concentration in the films, the tensile strength, contact angle, and cross-linking degree showed an improvement, whereas elongation at break and water vapor permeability reduce. Antioxidant capacity was enhanced by increasing the TP content in the films. The addition of TP into GSA films is an ideal choice to enhance an active edible and environmentally friendly packaging for the shelf life of food extending (Dou, Li, Zhang, Chu, & Hou, 2018).

Nabilah et al. (2019) investigated the effect of mangosteen pericarp extract (MPE) on fish gelatin (FG), corn starch (CS), and SPI films. MPE reduced the mechanical properties and increased the water vapor permeability of the films. Protein-based films have shown better mechanical properties compared to starch films. Corn starch films had good water resistance compared with protein-based films. In conclusion, MPE added in the FFS has enhanced functionality of soy protein films biodegradable film with a high antioxidant capacity may thus be a promising natural antioxidant to be used as an active film in packaging content. The results of another study by Rodriguez et al. (Rodríguez et al., 2020) demonstrated that papaya dried dehydrator edible films showed promising results in terms of their physicochemical properties, longer shelf-life under managed storage conditions and good sensory acceptance by panelists. The formulations added by Moringa provided an important nutrient for consumers considering its protein content. Enhanced papaya edible films are an efficient method for prolonging the shelf-life of oxidation-prone products, such as pears, due to their high antioxidant ability, which is why natural extracts are an appealing effect to the use of synthetic antioxidant utilized in the food industry. In addition, Moringa has had an interesting impact on the protein content of the edible films being made. Ultimately, the addition of both bioactive compounds showed an impact on the longevity of minimally processed pears 'shelf-life, with the edible film combined with ascorbic acid having a beneficial effect on the sensory acceptance of such a food matrix. In an aforementioned study Han, Yu, and Wang (2018a) on Bio-based films prepared with soybean by-products and pine (*Pinus densiflora*) bark extract, pine bark extract (PBE) has excellent antioxidant activity and is a good source of oligomeric procyanidins. Bio-based antioxidant films were prepared by adding different concentrations PBE into the SPI matrix. The structures of the films were rougher with PBE. Cross-linking interactions formed between the amino groups in the SPI matrix and the phenolic hydroxyl group in PBE. Also, PBE improved the thermal stability of the films. Antioxidant SPI films with PBE could be used in food packaging.

Table 11.2 summarizes the antioxidant activities of plant extracts in different packaging films.

Table 11.2 Antioxidant activity of plant extracts in food packaging.

Plant-derived	Packaging material	Packaged product	Process	Antioxidant compounds	Results	References
Chestnut extract	Chitosan film	Fresh pasta	Casting	Phenolic content	Total phenolic content show dependency on moisture throughout the shelf life, inhibited microbial growth during 2 months	Kõrge, Bajić, Likozar, and Novak (2020)
Pomegranate peel/ pistachio green hull extracts	–	Cooked sausages	–	Gallic acid, ellagic tannins and ellagic acid hydroxybenzoic acid, protocatechuic glucoside, acid, quercetin, naringin, and catechin	Showed great antioxidant activities reduced amounts of nitrite up to 50% in cooked sausages improve its functional properties	Aliyari, Bakhshi Kazaj, Barzegar, and Ahmadi Gavlighi (2020)
Amaranthus leaf extract	Polyvinyl alcohol and gelatin	Chicken/ fish	Casting	Phenolics: Total carotenoids, betacyanins. Flavonoids: Chlorophyll a, Betaxanthins. Tannins: Chlorophyll b, Betalamic acid	The film minimized oxidative rancidity of the products, ensuring its quality and safety, improved the antioxidant activity, prolong the shelf life	Kanatt (2020)
Sweet pepper extract	–	Canned refrigerated pork	–	Chlorogenic acid quercetin	Antioxidant capacity increased by the addition of extract. Antioxidant capacity of SPE as a canned pork additive to a reduced content of nitrite by half.	Ferysiuk, Wójciak, Materska, Chilczuk, and Pabich (2020)
Satureja thymbra extracts	Laminated film	Fried potato chips	–	Phenolic acids and flavonoids	Prooxidant activity at higher concentration delaying the deterioration of the fried product in active packaging	Choulitoudi, Velliopoulou, Tsimogiannis, and Oreopoulou (2020)
Olive leaf extract	Carrageenan films	Food product	Casting	Phenolic compounds	Exhibited good barrier properties and mechanical properties Had high antioxidant activity and has great potential for use as a functional ingredient in food packaging.	da Rosa et al. (2020)

Mangosteen (Garcinia mangostana L.) rind	Chitosan film	Soybean oil	Casting	Polyphenols	Inhibited the increase in the peroxide value and thiobarbituric acid reactive substances of soybean oil during storage enhancements in antioxidant ability	Zhang, Liu, et al. (2020)
Pine nut shell, peanut shell and jujube leaf	Chitosan film	–	Casting	5,7-Dihydroxychromone Eriodictyol Luteolin, Catechin, Epicatechin Quercetin, Apigenin Total phenolic and anthocyanin	Improved the antioxidant capacity of films reduced the homogeneity Three plant extracts had also changed the microstructure, chemical structure and thermal properties	Zhang, Lian, Shi, Meng, and Peng (2020)
Pomegranate peel	Mung bean protein film	Food product	Casting	Catechins, punicalin, pedunculagin, punicalagin, gallic acid, and ellagic acid	Significant effect on the TPC The mechanical properties, reducing power, anti-radical activity, and antibacterial attributes of mung bean protein films were improved	Moghadam et al. (2020)
Blood orange peel pectin	Fish gelatin	Cheese	Casting	Poly(1,4-galacturonic acid)	Improves the physicochemical, barrier and antioxidant properties	Jridi et al. (2020)
Moringa leaf extract	Papaya edible films	Pear	Casting	Flavonoids and phenolics contents	Lowest antioxidant activity, effect in the protein content of the developed edible films the in vitro antioxidant effect of moringa, both in DPPH assay and in contact with the pear, was rather limited	Rodríguez, Sibaja, Espitia, and Otoni (2020)

11.2.3 Biodegradable packaging aids

11.2.3.1 Polysaccharide-based films

Over the last few decades, synthetic films have grown rapidly in food production and applications, causing considerable environmental concerns because synthetic materials are resistant to degradation. Nowadays, consumers are looking to decrease environmental issues related to food packaging and health concerns, therefore, request biodegradable materials (Akhter, Masoodi, Wani, & Rather, 2019). Biodegradable and edible films due to their capabilities to prevent moisture loss, solute transport, aromas loss, water absorption in the food matrix or oxygen penetration could be a substitute for synthetic packaging materials in various applications. Hence, food scientists and engineers are seeking to develop new materials for an edible and biodegradable film focused primarily on the abundance of renewable resources. These materials are usually cheap and many are known as waste or by-products (Cazón, Velazquez, Ramírez, & Vázquez, 2017). The use of biodegradable polymers should be exploring continuously to replace the petroleum-based plastics in the food industry and to improve the shelf life of the products. The goal of biodegradable films and edible coatings is to reduce the loss of oxygen, moisture, and other gasses by promoting semipermeable barriers and increasing the shelf life of food (Sganzerla et al., 2020). Moreover, the researchers try to develop biodegradable alternatives that can be used as replacements for the existing synthetic polymers because of the environmental effect of using synthetic packaging materials as a vehicle for value-added. In addition, packaging films based on biopolymers provide multiple advantages due to their excellent biocompatibility, biodegradability, eco-friendliness and even edibility. In general, according to the source of the original polymer used, biopolymer films were classified (da Rosa et al., 2020).

Polysaccharides are feasible film-forming materials and an abundant natural resource between biopolymer materials. They have good properties as barriers, including carbon dioxide and oxygen, but poor water vapor barrier, a lot of researcher's attention has been paid to them (Alexandre et al., 2016). New opportunities to develop novel food packaging technologies may be provided by the application of polysaccharide films in food products. The film-forming ability of several polysaccharides has been studied, including cellulose, chitosan, starch, pectin, alginate, carrageenan, pullulan and kefiran. Polysaccharides such as cellulose derivatives, starches, chitosans, and gums have been known as raw material to prepare edible films and coatings that could be used for food protection as packaging material (Cazón et al., 2017). Proteins and starches have potential sources as natural polymers to formation biodegradable and edible films to replace petrochemical polymers widely used in the packaging field. The renewable sources are regarded to be promising polymers for packaging materials because they are readily available worldwide, inexpensive, biodegradability and nontoxicity. Starch-based films have a strong film-forming potential because of their potential to form a continuous matrix and their thermoplastic properties. Corn starch is one of the most used starches in food packaging applications because of its plentiful sources, renewability and low cost of this raw material (Nabilah et al., 2019). Renewable biodegradable polymers display a credible alternative to traditional oil-derived polymers in agricultural and packaging applications, to decrease environmental impact to enhance environmentally friendly sustainable, cost-effective products. Biopolymers are destroyed by the enzymatic activity of micro-organisms, such as bacteria, fungi and algae, when disposed of in bioactive environments and transformed into biomass, CO_2, CH_4, water and other natural substances. Biodegradable polymers can be synthetic or natural, depending upon their origin. Natural polymers, known as biopolymers, include microorganism-produced polysaccharides, proteins, and polyesters, while poly (vinyl alcohol) and polyesters are the most common of biodegradable synthetic polymers. Biodegradable polymers are limited in use and industrial development due to their poor chemical−physical properties, inadequate mechanical efficiency and difficult processability (Ju & Song, 2019b). A range of polysaccharides for potential application as edible packaging has been developed due to their abundant, low cost, edible, biodegradable, easy-to-handle, and good film-forming pro (Qin et al., 2019; Wyrwa & Barska, 2017). Hence, research has focused on biodegradable polymer systems. Starch is one of the most widely studied among biopolymers as it is broadly available and easily modified to produce thermoplastic polymers. However, thermoplastic starch applications are limited due to the hydrophilic nature responsible for rapid degradation through hydrolysis. In general, starch is modified by blending with synthetic polymers, such as polyesters or vinyl alcohol copolymers, to vanquish this experimental drawback (Cerruti et al., 2011). Native starch depending on the source of starch is extremely variable in its function and structure. The commercially used starches are obtained from many plant origins such as potato, wheat, cassava, corn and rice (Qin et al., 2019). Carrageenan is a polysaccharide natural product derived from seaweed (Wyrwa & Barska, 2017).

As an additive to a starch-based polymer (Mater-Bi), a polyphenol-containing extract from winery bio-waste (EP) was used by Cerruti et al. (2011). It was observed that the processing, mechanical, thermal, and biodegradation properties were effectively modulated by EP. Also decrease in melt viscosity has shown that EP could enhance the polymer processing productivity. Larger values of elongation at break were noticed because of the additive's plasticizing behavior. Eventually, doped Mater-Bi's bio-disintegration rate decreased, indicating that EP acted as an antimicrobial agent by interacting with the polymer film's bio-digestion. Kanmani and Rhim (2014a) developed antimicrobial packaging films based on natural biopolymers as an alternative for synthetic packaging films. The GSE has been incorporated into agar as a natural antimicrobial agent in various concentrations to prepare antimicrobial packaging film by casting method. With the addition of GSE the UV barrier, color, water solubility, moisture content and water vapor permeability increased, while a reduction in tensile strength, elastic modulus surface and hydrophobicity of the films was observed. The incorporation of GSE changed the film's microstructure but did not affect the agar-based films ' crystallinity and thermal stability. These findings indicate that agar/GSE films could be used to preserve food protection and increase the shelf-life of the packaged product in active food packaging systems. Comparative studies were done by Norajit, Kim, and Ryu (2010). In this research, the physical and antioxidant properties of biodegradable alginate film containing green, red, and extruded green ginseng extracts was studied. The highest moisture content of the ginseng extract was incorporated in film samples, but no differences in the moisture content of all alginate film samples were observed. The adding of ginseng extract to alginate film reduced elastic modulus and tensile strength but increased the percent of elongation at break. Such tests for free-radical scavenging operation were accompanied by film tests containing red and white ginseng extracts, respectively. These findings have shown that the extruded white ginseng extract has a strong potential to be integrated into alginate to create an antioxidant biodegradable film or coating for different food applications. Wyrwa and Barska (2017) reported that the addition of plant oils greatly improved the thickness of the film. Nevertheless, the moisture content, solubility and tensile strength of the film decreased dramatically as plant oils were incorporated. The addition of plant oils also led to a plasticizing effect, which significantly increased the elongation values at break. In conclusion, the plant oils used in this research greatly improved kappa-carrageenan films properties, thereby demonstrating the ability of these products to be used as films and coatings for food packaging. Other study aimed with to develop novel functional films based on chitosan (CS) containing Chinese chive root extract (CRE) by casting method. SEM showed that a higher concentration of the extracts triggered agglomerate formation within the films. The WVP has been reduced due to the good barrier property of CS-based CRE film. Additionally, overall color attributes have been improved from transparent to opaque. The films made by incorporating CRE into CS showed strong antioxidant and antimicrobial activity suggesting that it could be produced for the food industry as a bio-composite food packaging material (Riaz et al., 2020). Rubilar et al. (2013) demonstrated that mixtures of GSE and carvacrol can be added to a matrix of chitosan films. They successfully prepared transparent biodegradable films and the application of these natural agents affected the mechanical, barrier and color properties of the chitosan films. The addition of compounds such as GSE and carvacrol can also be used to protect foods from degradation caused by UV light. These films may also offer alternatives to synthetic materials, potentially leading to improved food safety and extended shelf-life. Sganzerla et al. (2020) studied the biodegradable packaging produced with pinhão starch and citric pectin used the agroindustrial waste of Acca sellowiana by-product (feijoa peel flour, FPF). Regarding the morphological, physicochemical, antioxidant and antimicrobial properties of the packaging, positive effects were achieved. The results obtained show that, for all the parameters tested, FPF addition had a positive effect on the packaging characteristics. The packaging that was developed retained apple consistency during storage, after 5 days of storage with constant weight. Based on their findings, the bioactive packaging can be considered as a potential alternative to food packaging. Da Rosa et al. (2020) analyzed the bioactive compounds from olive leaf extract and to produce biodegradable carrageenan films with antioxidant properties by adding varying olive leaf extract concentrations. The extract of MAE solvent-free olive leaf has a high antioxidant activity and has a high potential for use as a functional ingredient in food packaging. Given the addition of extract to biofilm resulting in a slight increase in stretching capacity, reduced tensile strength and increased water vapor permeability, the carrageenan-based biodegradable films containing olive leaf exhibited strong barrier properties and mechanical properties. With an increase in concentration of olive leaf extract, the overall phenolic compounds and antioxidant content of films dramatically increased. The addition of natural antioxidants appears to be a possible technique for applying additives to food-suitable packaging materials. In a study investigating the optical and antioxidant and mechanical properties of funoran films containing various concentrations of yellow onion peel extract (YOPE) (0.3%, 0.5%, and 1.0%), Ju and Song (2019b) reported that after YOPE's addition, the total phenolic and flavonoid content of the funoran films increased. These results indicate that the funoran-based film combined with YOPE, prepared from underused red algae and discarded onion peel, can be used as a biodegradable packaging material with antioxidant benefit. In a study conducted by Ju, Baek, Kim, and Song (2019), it was shown that the develop and characterize the properties of Khorasan wheat starch (KWS) films with addition of moringa leaf extract (MLE). The isolated KWS from Khorasan wheat was mixed with Different amounts of MLE and the film properties were investigated. With increasing MLE content elongation at break increased and tensile strength of the KWS films reduced. KWS films including MLE revealed acceptable antioxidant and ultraviolet light-blocking properties. Moreover, KWS films containing 1.0% MLE were biodegradable within 30 days. The result suggested that Developed KWS film containing MLE may be used as a biodegradable packaging material with antioxidant activity. Three plant extracts (pine nutshell, peanut shell and jujube leaf) enhanced the antioxidant capacity of chitosan-based biodegradable films. Compared to control films, the DPPH radical scavenging activity of chitosan-jujube leaf films 3.8-times increased. The chitosan film with incorporation of pine nutshell had the greatest oxygen permeability and water vapor, while chitosan film with adding peanut shell demonstrated the highest increase in CO_2 permeability and the highest thermal stability. However, three plants extract decreased homogeneity and induced chitosan film porous structure. The research presented a target for preparing high antioxidant and gas-permeability polysaccharide-based active films (Zhang, Lian, et al., 2020). In an investigation into a teff starch (TFS) biodegradable film was enhanced with incorporation of camu-camu extract (CCE), Ju and Song (2019a) found the TFS films with CCE revealed great radical scavenging activities. With increasing CCE content, the elongation at break increased, whereas the tensile strength of TFS films decreased. The TFS films containing CCE completely blocked the ultraviolet light in the 200−360 nm range. In addition, the surface of the TFS films became rough and the contact angle of the TFS films increased from 36 angle to 69 angle as the amount of CCE incorporated increased. These results indicate that TFS films containing CCE could be used as an antioxidant packaging material in food industry. A significant analysis and discussion on develop polylactic acid biodegradable packaging materials (PLA) and extracted starch from cassava tubers was presented by Kaushalya, Dhanushka, Samarasekara, and Weragoda (2019). Biodegradable PLA and starch-based blends were prepared through incorporation starch as the main additive. During the soil burial test, weight loss in starch-containing samples increased slowly with time. Experimental findings also revealed that product biodegradability increased, and mechanical properties such as tensile strength and elongation also decreased with adding starch content. These results showed that the incorporation of starch to PLA can be a good method for enhancing the biodegradability of PLA—starch blends.

11.2.3.2 Protein-based films

Food packaging is an essential mechanism in food processing and plays a major role in preserving the food from possible contaminations, protecting the quality of the food, and extending its shelf life during preparation, transport, and storage (Han, Shin, Park, & Kim, 2015; Yuan et al., 2020). If the packaging material can not completely prevent moisture from entering properly, there would be a reduction in shelf-life due to the degradation and spoilage of the product and ultimately result in soggy foods. Besides, microbial contamination and lipid oxidation may happen after food packaging, and these have become the main problems in the food industry. Therefore, the development of food packaging materials has been growing up significance with the quick progress of the global food industry (Han et al., 2015). The use of non-edible and non-biodegradable synthetic products for food packaging, such as polyamide and polyethylene, causes significant environmental issues and imposes several health risks (Jridi et al., 2020; Tulamandi et al., 2016). In addition, Synthetic films contained harmful molecules, which, when added to the surface, would migrate to the food product. Therefore, scientist efforts to search for new packaging from biodegradable, natural and sustainable biopolymers have been increased. Natural biopolymers are known as a potential source for the development of new food packaging materials and eco-friendly (Hoque, Benjakul, & Prodpran, 2011; Jridi et al., 2020). In last few years, food-packaging industries have indicated an interest in edible films. According to environmental and consumers health concerns, conventional plastic packaging is replaced by edible and biodegradable biopolymers films. Edible films also enhance the quality of food by providing barriers to moisture, gas, and oxygen they have been used during storage to preserve the quality of the food (Alexandre et al., 2016; Jang et al., 2011). Food characteristics can be provided by edible coatings based on these natural materials, performing as an excellent barrier to water vapor and oxygen and enhancing their physicochemical, microbial, and sensory properties.

Protein film-forming ingredients are various and can be easily obtained from sources of animals and fish, such as collagen, whey protein, and gelatin (Jridi et al., 2020). The physicochemical properties of proteins depend entirely on the arrangement and relative amount of amino acid substitutes alongside the chain of the polymer (Hassan, Chatha, Hussain, Zia, & Akhtar, 2018). Materials based on protein are typically biodegradable and derived from the sources of renewables. Protein-based films have appropriate optical, mechanical and oxygen barrier characteristics while because of its hydrophilic nature have a high sensitivity to moisture and low water vapor barrier properties (Zink, Wyrobnik, Prinz, & Schmid, 2016). Thus due to its biodegradability, good gas barrier property and oil resistance capacity, protein-based films have gained more attention these last years (Insaward, Duangmal, & Mahawanich, 2015).

Moreover, gelatin has a linear structure and minimal monomer composition, contributing to excellent film-forming and is biodegradable (Abedinia et al., 2020; Oladzadabbasabadi, Ebadi, Mohammadi Nafchi, Karim, & Kiahosseini, 2017). Gelatin is a highly processable substance and sensitive to moisture.

Some authors have driven the further development of bioplastic materials for food packaging by the addition of a natural antioxidant agent into films based on soy protein Han et al. (2015). The films were prepared by SPI with incorporation catechin (CT) and/or carboxymethylcellulose (CMC). The original SPI film turned opaque after being blended with CMC or CT, whereas the original SPI film showed good optical transparency. The SPI film with CMC exhibited improved tensile strength and water solubility and reduced percentage of elongation and water vapor permeability as compared with pure SPI film. The CT-incorporated SPI or SPI/CMC films also revealed a synergistic, free radical scavenging effect. The results indicated that the bioplastic soy protein-based film produced in this study could be used in the food industry as a potent antioxidant packaging material.

Rapeseed protein–gelatin edible film containing antimicrobial GSE has been developed to manufacture a packaging film for "Maehyang" strawberries. The incorporation of GSE to the protein—gelatin (RG) rapeseed film inhibited pathogenic bacteria growth. GSE-RG film-packaged strawberries provide better sensory scores than the control. These findings indicate the GSE- RG film can be used for packaging strawberries and extending the shelf life (Jang et al., 2011). Previous research by Jridi et al. (2020) showed that the efficacy of the incorporation of gray triggerfish gelatin and blood orange peel pectin resulting in enhanced composite film properties as demonstrated by thermal, mechanical, and structural analysis. In addition, the blend film demonstrated strong antioxidant and antibacterial properties compared to the gelatin-based film. The composite films have double positive benefits according to their fascinating biological activities, either by improving the microbial consistency of cheese during cold storage or by offering consumer health benefits. Recent findings suggest the further use of gelatin pectin films as active packaging material in the food industry. In another study, the mixed of gelatin and defatted soy protein to the papaya films had enhanced the barrier, mechanical, optical properties as well as structural properties. The optical properties were similarly comparable with the packaging materials based on polymers. Higher seal strength and tear strength suggested the use of edible films for functional packaging. The best indices for correlation between polymeric materials are the thermal properties of papaya edible films. It is reported that there were highly important edible film properties in the combination of 8 g papaya puree, 3 g gelatin and 4 g defatted soy protein composite films (Tulamandi et al., 2016).

The effect of incorporating blueberry-extract into a soybean-protein-isolate edible film on the consistency of packaged lard was compared with individual incorporations of vitamin E or butylated hydroxyl anisole (BHA) during storage at 36C and relative humidity at 40% over 5 weeks by lard. The incorporation of blueberry extract into soybean-protein-isolate film demonstrated higher tensile strength and lower oxygen and water vapor permeability than individual incorporations of vitamin E or BHA. At the other side, the soybean-protein-isolate film's antioxidant potential integrated with the blueberry extract was greater than that integrated with vitamin E, and comparable to that incorporated with BHA. Therefore, blueberry-extract incorporations in the soybean-protein-isolate film not only strengthened mechanical and barrier properties but also delayed packaged lard's oxidation and hydrolysis. These films have potential as a packaging material that protects the quality of stored lard (Zhang et al., 2010)

A recent study by Yuan et al. (2020) has found that the combination of oolong tea, corn silk, and black soybean seed coat to shrimp shell, protein-based films not only could change the physicochemical properties of the final film but also improve its antioxidant activity. The resulting films with increased antioxidant of complete marine origin would be promising for application in several types of foods.

Hoque et al. (2011) concluded that partially hydrolyzed gelatin incorporation with herbal extracts containing clove, cinnamon, and star anise extracts showed enhanced TS and decreased WVP. Nevertheless, to some degree, those extracts may affect the color of the resulting films. Star anise extract became the most effective to enhance the gelatin film's mechanical and water barrier properties. Oxidation extracts demonstrated greater efficiency than the non-oxidized equivalent in increasing the strength of the films. However, the molecular weight or length of the gelatin chain has been implicated in the cross-linking of phenolic compounds in the extracts as well as the microstructure of the resulting film. Herbal extracts may be used as natural protein cross linkers capable of modifying the properties of gelatin film or other proteins. Thus the incorporation of various herbal extracts directly affected the film properties with and without hydrolysis of cuttlefish skin gelatin.

In a recent study, collagen hydrolysate (CH) films were developed by addition of thyme essential oil (TO). Incorporating of TO led to increases in the thickness, elongation at break (%), and light barrier performance of CH—TO films as well as there was a considerable reduction in film solubility and tensile strength of the CH films. Moreover, the increase of TO showed higher lightness and yellowness while lower redness amount compared to CH film observed hence they can be used for active packaging purposes (Ocak, 2020).

Also, Mohammadi, Mirabzadeh, Shahvalizadeh, and Hamishehkar (2020) enhanced a biodegradable whey protein isolate-based film incorporated with cinnamon essential oil and chitosan nanofiber, and the antibacterial activity of films was improved by incorporating cinnamon oil.

11.2.4 Active packaging aids

The demand for food products has risen over recent years and can long sustain their quality, which leads to a decline in economic losses and health issues caused by food spoilage. While the use of chemicals increases food shelf life, it is not considered nutritious or safe and is avoided by consumers (Eskandarabadi et al., 2019). Over the last few decades, synthetic film development and use in food packaging have increased rapidly, leading to significant environmental issues as synthetic plastics are not degradation (Cazón et al., 2017). Currently, the growing demand for healthier and safer food has led to new preservation methods being investigated (Gómez-Estaca, López-de-Dicastillo, Hernández-Muñoz, Catalá, & Gavara, 2014).

As a response, a refined and enhanced protective feature of packaging has led to the evolution of modern packaging innovations such as active packaging (Yildirim et al., 2018). The principle of incorporation in packaging system of certain components that release or absorb substances from or into the packaged food or the surrounding environment to extend shelf life and preserve the consistency, health and sensory characteristics of the foodstuff (Realini & Marcos, 2014).

Natural sources such as GTE (Mujeeb Rahman et al., 2017; Peng et al., 2013; Siripatrawan & Harte, 2010; Wambura, Yang, & Mwakatage, 2011; Wu et al., 2013), olive leaf extract (Amaro-Blanco, Delgado-Adámez, Martín, & Ramírez, 2018; da Rosa et al., 2020), mango kernel extract (Maryam Adilah et al., 2018), rosemary extract (Eskandarabadi et al., 2019), mangosteen pericarp extract (Nabilah et al., 2019; Zhang, Liu, et al., 2020), murta fruit and leaf extract (Hauser et al., 2016; López de Dicastillo et al., 2016; Silva-Weiss, Bifani, Ihl, Sobral, & Gómez-Guillén, 2013), blueberry extract (Gutiérrez & Alvarez, 2018) moringa leaf extract (Ju et al., 2019) camucamu extract (Ju & Song, 2019a) onion peel extract (Ju & Song, 2019b), Rheum ribes L. extract (Kalkan et al., 2020) Chinese hawthorn fruit extract (Kan et al., 2019), GSE (Kanmani & Rhim, 2014a, 2014b; Shankar & Rhim, 2018; Song et al., 2012; Tan et al., 2015; Wang, Lim, et al., 2019), plant extracts (Bonilla & Sobral, 2016; Kraśniewska et al., 2014; Mir, Dar, Wani, & Shah, 2018), ginger essential oil (Alexandre et al., 2016), hemp and sage oils (Mihaly Cozmuta et al., 2015), oregano essential oil (Chen et al., 2020; Lee et al., 2016), and plant oils (Wyrwa & Barska, 2017) are some examples of plant extracts that have been used in the development of food packaging.

Fish gelatin films prepared with mango peels extract (MPE) with three different concentrations of 1%−5% by casting method caused excellent free radical scavenging activity by Adilah et al. (2018). Films incorporated with MPE exhibited a reduction of water vapor permeability and fewer films solubility. Also, the more rigid and less flexible film formation observed with a high level of MPE. This study showed that the mango peel extract incorporated into gelatin-based films could be used as a potential material for active packaging.

Active packaging with olive leaf extract was not effective in preserving the iberian sliced dry-cured shoulder, either alone or in combination with HPP. The more lipid-soluble active principle could probably be more effective for Iberian dry- products due to their high lipid content. The high stability of this product would probably be somewhat responsible for the quality characteristics of the shoulders of pigs reared in Montanera (Amaro-Blanco et al., 2018).

A comparative study on natural plant extracts as active components in chitosan-based films was done by Bajić, Ročnik, et al. (2019) were done. Extracts obtained from oak three, hop plant and algae were added separately to the films for evaluated and mutually compared. Of the blended films, the film containing the oak extract had fewer amount of water and total soluble matter in addition to the highest phenolic content. This ultimately led to the creation of material with desirable mechanical properties in the lowest pliability and the highest strength and stiffness relative to the other two blended films. It can be claimed that the OE film overcomes the performance of HE and AE films. Therefore, it has a high potential to be used as active food packaging material made from natural-based materials.

Effect of active packaging containing Satureja thymbra extracts on the oxidative stability of fried potato chips evaluated by Choulitoudi et al. (2020) Satureja thymbra extracts that have rich in phenolic acids and flavonoids, were gained with ethyl acetate and ethanol by successive extractions and analyzed as natural antioxidants to extend the shelf- of fried potato chips. The extracts were more effective when spraying them on the fried product surface or adding to the frying oil when coated on a laminated film used as active packaging for the chips. Partial migration was observed of the natural polyphenols into the product.

The incorporation of GTE into the film-forming solution produced active biodegradable films based on agar and agar-gelatin. Agar-gelatin films were less resistant than agar films and more deformable. The use of GTE in both agar and agar gelatin films reduced the tensile strength and elongation at break. Water vapor permeability and water resistance were not impaired either by the substitution of agar with gelatin or by the addition of GTE. But the water solubility in films containing GTE improved significantly. Total phenolic compounds, catechins and flavonols not released into the water, which was reported due to the presence of gelatin in the Green Tea Matrix Agar film. As a result, the antioxidant power released by the films was lower for gelatin-containing films. Nevertheless, the presence of gelatin did not affect the antimicrobial activity of the films (Giménez et al., 2013).

Characterization of SPI films containing licorice residue extract was made by Han, Yu, and Wang (2018b). Through adding liquorice residue extract (LRE) into SPI films were made antioxidant films. They have investigated the effects of different concentrations of LRE on the physical properties, microstructure and antioxidant activity of SPI films. Evaluation of FTIR suggested the formation of hydrogen bonds between active protein matrix groups and phenolic hydroxyl LRE groups. Adding LRE enhanced the film's mechanical, water-, oxygen-, and light barrier as well as antioxidant properties. The water affinity of the films was still strong, due to the hydrophilic nature of SPI films. TPC release test showed that, due to the rapid swelling of the hydrophilic matrix in 10% ethanol, the release rate of TPC from active films into 95% ethanol was slower than in 10% ethanol. SPI films containing LRE have a high potential as an active packaging material to preserving fatty foods.

A new active packaging film was made based on murta leaf extract which was inserted into a layer of methylcellulose that was based on polyethylene (LDPE) film that was low density. They were observed slight changes in the color, optical and mechanical properties; although, thermal and water vapor transmission properties did not change through the active coating on the LDPE film. Eventually, a sensory analysis revealed that the active coating did not affect the odor and flavor properties of a fatty food packed within the active substances. It indicates that this active packaging film could be used to expand packaged food's shelf-life (Hauser et al., 2016).

The effect of the polyphenolic extract of N. sativa seeds was evaluated on the functional property of edible chitosan film by Kadam, Shah, Palamthodi, and Lele (2018). The changes in bonding between CH−CH and CH-water and the presentation of CH−NSE interactions led to considerable changes in the crystallinity, WVP, mechanical properties and thermal characteristics of chitosan films. This suggests that it could be used in active packing based on the requirements of a particular packaging.

Kan et al. (2019) developed active packaging by polyphenols that was extracted from the fruits of Chinese hawthorn and further added into chitosan-gelatin blend films. Investigated the microstructure, physical, mechanical, barrier and antioxidant properties of the films were revealed that procyanidin B2, chlorogenic acid and epicatechin were the main polyphenols in the hawthorn fruits extract. When the extract was incorporated, the inner microstructure of chitosan-gelatin blend films became more compact. The addition of extract significantly increased the tensile strength, thickness, and elongation at break of chitosan-gelatin blend films. However, the water vapor permeability, moisture content and light transmittance of chitosan-gelatin blend films were remarkably decreased by the incorporation of the extract. Also, chitosan-gelatin blend films containing the extract have ability the potent of free radical scavenging. In the consequences, they suggested the extract of Chinese hawthorn fruit could be used to enhance the barrier, mechanical and antioxidant properties of chitosan-gelatin blend films as a natural antioxidant.

Active films were made from polyvinyl alcohol (PVA) and chitosan (Ch) incorporating pomegranate peel extract (PE) and aqueous mint extract (ME) by Kanatt, Rao, Chawla, and Sharma (2012). Incorporation of extract into the films increased protection against UV light. The tensile strength of the films was enhanced by the addition of ME/PE. The highest tensile strength was observed in the Ch-PVA films incorporated with PE. The results demonstrated that the Ch-PVA film incorporating ME/PE could be used for the improvement of active packaging.

In another study, carrageenan-based films were developed by the addition of GSE at different concentrations, and their physical and mechanical properties were investigated by Kanmani and Rhim (2014b). Polyphenolic compounds in the GSE led to the carrageenan/GSE composite films appeared yellowish tint. SEM analysis showed on the cross-section of the films, rough surface with sponge-like structures. Based on the FT-IR results, it can be concluded that the GSE is in good compatibility with the carrageenan. The amorphous structure of polymer films has remained constant by the incorporation of GSE. While the incorporation of GSE increased water vapor permeability, moisture content and surface hydrophilicity of the films. As the GSE content increased, the tensile strength and elastic modulus decreased. The thermal stability of the film did not change with the addition of GSE. This suggests that carrageenan-based composite films with GSE could be used in active food packing application.

Active films were made of polylactic acid (PLA) containing different concentrations of an Allium spp extract to developed packaging of ready-to-eat salads (Llana-Ruiz-Cabello et al., 2015). At the incorporation of the active material, the mechanical and optical properties of PLA films did not exhibit significant changes. Also, no remarkable antioxidant activity was recorded, although significant antimicrobial activity was observed, mostly in films containing 5% and 6.5% of the Allium spp. extract. Relating to aerobic bacteria, the film with the highest active agent concentration (6.5%) was effectual for up to 5 days of storage, as well as 7 days for molds. Thus, this film could be used as active packing, especially for ready-to-eat salads.

Active films based on methylcellulose (MC) and murta fruit extract (MU) were prepared by the casting method of Lopez de Dicastillo et al. (López de Dicastillo et al., 2016). The addition of GA and MU had a slight effect on thermal properties. The incorporation of GA notably reduced swelling index and enhanced mechanical properties. Antioxidant and antimicrobial activity reached optimum efficiency when GA was applied at the lowest amount.

Kanatt and Chawla (2018) demonstrated that mango peel has bioactive compounds, and that Langra peel had the strongest antioxidant and antibacterial activities among the four varieties tested. An active composite film was developed from PVA cyclodextrin-gelatin with addition LMPE. During the film formation process, the bioactive properties of LMPE were retained. UV-blocking and mechanical properties of the film enhanced with the incorporation of LMPE. When kept at chilled temperatures, the shelf life of chicken meat packed in these films was increased by 10 days. Although 80% acetone and 70% ethanol extract of LMP were effective as an active ingredient in film, aqueous ethanol extract is preferred for food packaging films. The film produced has the potential to act as an active film for food packaging and to reduce the burdens of food packaging waste dependent on petroleum.

11.2.5 Intelligent packaging aids

The packaging is a critical part of modern trade, which assigns the protection of the quality of food products and is one of the most important means of advertising. In fact, it performs the main task by safeguarding the packaged product against environmental factors, affecting its consistency and health, and promoting transport, storage, and dosing. Besides, new packaging technologies are expected to play an increasingly important role by providing various and innovative prolong the shelf-life solutions. Active and intelligent packaging is a modern idea, provided for further enhanced food product safety and control (Balbinot-Alfaro et al., 2019). Mainly, intelligent packaging technology is mighty of providing functions such as detecting, recording, monitoring, communicating, and applying scientific logic to promote decision-making, improve protection, enhance quality, as well as provide information and warning about potential issues (Alexandre et al., 2016; Balbinot-Alfaro et al., 2019; Ezati & Rhim, 2020). While the share of so-called advanced packaging is projected to represent approximately 5% of the packaging market's total value but there are signs that its sales will develop rapidly in the following years. The sum of patent applications and patents awarded represents the competition in these solutions (Balbinot-Alfaro et al., 2019). In the past few years, smart (active and intelligent) packaging systems based on biopolymers and natural extracts have recently attracted growing interest within the food industry (Yong, Wang, Bai, et al., 2019). This type of packaging system is not only intended to ensure food protection, quality and prolong shelf life but also to reduce the negative effects on the environment and improve health safety. Moreover, intelligent packaging is one type of smart material packaging system, which can provide consumers with information on the current food conditions within the packaging. Indeed, intelligent packaging serves as a communicator between the packaged product and the customer (Jamróz et al., 2019). Several kinds of intelligent packaging systems exist which are depending on the use of sensitive dyes, for example, time-temperature sensors (Pavelková, 2013; Pereira, de Arruda, & Stefani, 2015), pH indicators (Peralta, Bitencourt-Cervi, Maciel, Yoshida, & Carvalho, 2019) and freshness sensors (Kuswandi et al., 2011).

Traditionally, food packaging functions include four categories: containment, protection, convenience, and communication (Jamróz et al., 2019). As today's society has become more complex, they are not adequate for our society's quality standards. Novel concepts for intelligent packaging have been developed respond to the rising concerns of consumers about food safety and quality. Intelligent packaging is described as a food packaging system capable of monitoring and informing consumers in real-time about the food conditions. As pH changes are a significant factor in informing spoilage in many food items, numerous attempts have been made to enhancement visual pH indicators, as one type of intelligent food packaging system, due to several advantages include small size, high sensitivity, and lower cost (Choi, Lee, Lacroix, & Han, 2017). The pH indicators are applied for monitoring the freshness of stored food via changes in atmospheric pH that occur during food spoilage. It is good for the consumer, who gets clear information without opening the package about the freshness of the product (Alexandre et al., 2016; Jamróz et al., 2019). A pH change can be observed when food process deterioration occurs. Thus, allows pH changes to be used as indicators of food quality as they indicate the product status. In intelligent packaging, colorimetric pH indicators can be combined in packing and monitored by visual changes in color. Natural pigments responsible for blue, purple, violet, or red coloration in fruit and vegetables may be used as natural indicators for the changes of pH which known as anthocyanin (Andretta, Luchese, Tessaro, & Spada, 2019).

A colorimetric pH indicator film was enhanced using agar, potato starch, and natural dyes extracted from purple sweet potato, to form pH indicator films. Potato starch and agar as a biodegradable material were used to immobilize anthocyanins which extracted from purple sweet potatoes, Ipomoea batatas. Hence, the developed pH indicator films have great potential to assure food safety and detection of food spoilage as a diagnostic tool. Also, it has potential in the intelligent food packaging application (Choi et al., 2017). The colorimetric pH indicator film application was investigated with immobilized black chokeberry pomace extract in chitosan by Halász and Csóka (2018). During this analysis, various quantities of pomace extract from black chokeberry were incorporated with chitosan to prepare colorimetric pH indicator films. The pomace extract contained sufficient active ingredients to greatly reduce the solubility and swelling of chitosan. The indicator films retained their integrity even at acid pH due to the interactions between the polymer chains and the extract's phenolic components. Increased resistance to water was observed with higher extract content, which also resulted in reduced dye migration. The immobilized dye in chitosan films reacted well to the change in pH and showed a high difference in color from pH 1 to pH 10. Recently, a novel colorimetric pH indicator film was developed using agar and natural dye extracted from *Arnebiae uchroma* root by casting/solvent evaporation method. Enhanced colorimetric indicator films have revealed high potential as "real-time" intelligent packing for the convenient, anti-destructive and visual monitoring of fish spoilage due to their non-toxicity and visible color response (Huang et al., 2019). In other study, the fish spoilage test evaluated by microbiological analysis showed that between 6th and 10th days of storage the fish was spoiled. The film's color changes were not sufficient to effectively notify the trained sensory panelists about the spoilage of the stored Atlantic mackerel (Jamróz et al., 2019). Jancikova, Jamróz, Kulawik, Tkaczewska, and Dordevic (2019) studied the effect of rosemary extract from dry leaves (DRE) and fresh leaves (FRE) on intelligent and active properties of furcellaran (FUR), gelatin hydrolysate (GELH)-based film. Water content, tensile strength, and thickness were increased with the addition of rosemary extracts into FUR/GELH films. The incorporation of rosemary extracts into the FUR/GELH matrix improved the UV barrier properties of the tested films. The antioxidant activity (DPPH and FRAP) has not changed with the addition of FRE while notably increased with the addition of DRE. Color changes in varying pH have been noted; moreover, the fish spoilage test has shown that these films are not acceptable as an intelligent film to control the freshness for this sort of food product. Li et al. (2019) enhanced a novel pH-indicating based on chitosan and surface-deacetylated chitin nanofibers (CN) with incorporation of purple potato extractions (PPE). The Fourier transform infrared spectrophotometry (FT-IR) and differential scanning calorimetry results showed that PPE was effectively joined to the chitosan film. In contrast, higher CN content did not further enhance mechanical properties and due to aggregation in the films, CN would distribute unequally. Besides the ability to indicate pH, CS-CN-PPE has demonstrated exceptional antioxidant activity, and this presents a further advantage to the packaging of oxidized substances. The existing literature on the effects of purple onion peel extract (POPE) on the rheological properties of the *Artemisia sphaerocephala* Krasch, gum ASKG film-forming solutions was investigated. The rheological findings showed that the solutions-formed films were non-Newtonian fluids. Results of FTIR revealed that hydrogen bonds formed between POPE and ASKG compromise with rheological findings. The results of the TGA showed that the POPE reduced the stability of the films whereas The SEM observation showed a homogeneous cross-section of the films developed. Adding POPE reduced the film's TS, EB, WVP and light transmission rate. In buffer solutions the film color changed from red (pH 350 3.0) to brown (pH 11.0). The results indicated that ASKG films which contain POPE display great potential as intelligent packaging materials (Liang, Sun, Cao, Li, & Wang, 2018). A recent study by Liu et al. (2019) involved characterization fish gelatin-based film and haskap berries extract as active and intelligent packaging. In this research, to produce active and intelligent packaging films, polyphenols were obtained from the haskap berries and incorporated with FG. Results showed that the major polyphenols in the haskap berry extract (HBE) were anthocyanins and phenolic acids. FG film's crystallinity has been improved by incorporating HBE. In addition, the addition of HBE notably increased some factors such as water vapor, tensile strength, total color difference value and UV—vis light barrier properties and antioxidant ability of FG film. The results demonstrate that FG-HBE films can be used in the food industry as novel antioxidant and intelligent packaging. Ma, Liang, Cao, and Wang (2018) published this study aimed to prepare an intelligent film based on PVA, chitosan nanoparticles (CHNPs) with incorporating of mulberry extracts. Throughout the fish spoilage cycle, this film also changed from red to green, showing that it can detect changes in fish quality. The results suggested that films have great potential application as an intelligent film to detect food spoilage. Owing to their biodegradability and accessibility from reproducible materials, bio-based films have become preferred. The *Vitis amurensis* husk is a white-wine processing by-product. By integrating *V. amurensis* husk extracts into the tara gum/cellulose matrix, a new bio-based intelligent colorimetric film was made. This research shows that an intelligent colorimetric film can be used as a visual indicator for assuring food safety (Ma, Ren, Gu, et al., 2017). Intelligent packaging technology was improved based on film (gelatin, starch, and chitosan) as a natural polymeric, including aqueous hibiscus extract (HAE) bioactive compounds by Peralta et al. (2019). Under various pH conditions, anthocyanin, a compound present on HAE, changes the color. In the area of the intelligent packaging technology, the application of HAE as a natural pH indicator with noticeable color variation integrated with renewable materials to allow quick, economical, and easy. In another study, researchers enhanced and characterized a time-temperature indicator (TTI) of PVA/chitosan-based polymer film interfered with anthocyanins to indirectly specify changes in food quality by monitoring changes in the pH of packaged food products when subject to inappropriate storage temperatures. The TTI was made from *Brassica oleracea var.capitata* (Red Cabbage) extract as anthocyanins, chitosan and PVA. The developed TTI offers attractive features for application in intelligent food packaging due to its physicochemical specifications. The application of the TTI presented here is accompanied by an activation test on pasteurized milk, with obvious changes in the coloring of the film, which is necessary to show consumers that the product has undergone changes in its chemical composition (Pereira et al., 2015). Qin et al. (2020) improved intelligent and active packaging. The starch/polyvinyl alcohol film that contains 1.00 wt.% of the betalains-rich red pitaya *(Hylocereus polyrhizus)* PE has become more sensitive to ammonia than other films. Once used to monitor shrimp freshness, the film containing 1.00 wt.% of the extract shows noticeable color variations during the shrimp spoiling process due to the compacted volatile nitrogen compounds. The findings revealed that betacyanins were the main components of the extract, which showed significant changes in color under alkaline conditions. These findings indicated the film that contains 1.00 wt.% of the extract has the potential to utilized as active and intelligent packaging. Yong, Liu, et al. (2019) prepared pH-sensing films based on chitosan and incorporation of anthocyanin-rich, purple-fleshed sweet potato extract (PSPE). Based on the mass spectroscopic analysis, eight main compounds in PSPE were known as anthocyanins. PSPE could change its colors with increasing pH due to the plenty of anthocyanin content. PSPE incorporation could dramatically increase chitosan film thickness, water solubility, UV−vis light barrier property and thermal stability, Whereas the moisture content, elongation at break and crystalline character of chitosan film could decrease. Chitosan-PSPE films can also be used as antioxidant and intelligent pH-sensing films to prolong the shelf-life and track the consistency of food products. In the same study, Yong, Liu, et al. (2019) developed pH-sensitive based on chitosan by adding black and purple rice extracts. With the incorporation of PRE or BRE into the CS matrix, active and intelligent packaging films were successfully developed. The addition of a low content (1 wt.%) of PRE or BRE greatly improved the water barrier property and TS of CS film due to the hydrogen bonds formed between CS and the extract. Besides, the incorporation of PRE or BRE greatly improved CS film's light barrier and antioxidant ability due to the polyphenol in the extract. The reason for the pH-sensitive property of CS-PRE and CS-BRE films to the plenty anthocyanins in the extract has been reported. CS-BRE films showed stronger water vapor permeability, antioxidant properties and UV−vis light barrier than CS-PRE films at the same extract incorporation levels. CS-PRE films were ideally suited for monitoring pork spoilage due to moderate anthocyanin content. They suggested that CS-PRE films could be used for packaged food to monitor the freshness of product as an intelligent packaging. The production of cassava starch films without and with the incorporation of blueberry residues was carried out successfully by thermocompression. The colorimetric analysis demonstrated the potential use of blueberry residue anthocyanins as a color change indicator due to a modification in the pH value of the food product by altering the film color. Therefore, the film with blueberry could be used as intelligent packaging due to the phenolic compounds (Andretta et al., 2019).

11.3 Conclusion and further remarks

In summary, recent research has shown that plant extracts are awesome candidates to be used as packaging aids. The active components in some plant extracts have antimicrobial or/and antioxidant activities to be used as active packaging agents to improve the shelf life of foods. Some other plants are rich in anthocyanin components that are sensitive to pH changing and can detect food spoilage, especially in animal-based food products as an intelligent packaging agent. Meanwhile, the plant extracts are sensitive to heat and light. Food packaging materials mostly produce in high temperature processing. So, future research is essential in the area of stabilizing the active components from common plant sources or finding alternative plants to extract more stable active agents.

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