Biomass Conversion and Biorefinery (2024) 14:13731–13746
https://doi.org/10.1007/s13399-023-04044-9

REVIEW ARTICLE

Propolis applications in food industries and packaging

Mohamed El-Sakhawy[1] · Ahmed Salama[1] · Salah A. A. Mohamed[2]

Received: 11 September 2022 / Revised: 26 February 2023 / Accepted: 7 March 2023 / Published online: 16 March 2023

Abstract
Propolis has been utilized as a natural bio-product from beekeeping for various applications such as wound healing, food packaging, and food production. However, the applications of propolis as food additives are limited by the low oral bioavailability, bitter taste, and aroma. The current review investigates the recent techniques, such as encapsulation, microencapsulation, film casting, and composite materials, which enhance the propolis availability for food applications. Propolis enhances the mechanical properties, oxygen and moisture barrier, antioxidant, and microbial resistance of the resulting materials. Therefore, the utilization of propolis composites as an effective food packaging in the future is promising. Based on these results, the food industry can benefit from developing propolis-based composite.

Keywords Propolis · Food additive · Encapsulation · Feed · Packaging

1 Introduction to propolis

In recent years, technological advances in biomaterials have sparked considerable interest due to the extensive number of useful and valuable applications, such as tissue engineering, heavy metal removal from the environment, drug delivery, and food storage [1–3]. Propolis was reported as natural material extensively applied in traditional and alternative medicine and other bee products [4]. Propolis has been used as an effective anti-bactericidal, antiviral, and antifungal bio-product in treating human inflammations [5]. The composition of propolis varies depending on where and when it is collected and differs owing to the plant source [6]. Honeybees collect it from the leaf buds of different tree species, and it contains more than 160 identified components, among which phenolic compounds, mostly flavonoids, are the main components [7]. Propolis contains antioxidants that prevent oils and serum lipoproteins from oxidizing [8].

Propolis, bee glue, is a wax-like natural resinous material produced by bees by mixing plant resins with bees' saliva, wax, and pollen to produce the last material which is utilized by honeybees as a protective coating for the inner walls of the beehive [9]. Figure 1 shows the chemical composition of propolis, which contains resins (50%), composed of flavonoids and phenolic acids; waxes (up to 30%), essential oils (10%), pollen (5%), and other organic substances (5%), are usually included. The raw propolis, aqueous extract, and ethanolic extract were proven antimicrobial reagents due to their polar phenolic substances, especially the flavonoid portion [10].

Table 1 shows some phenolic compounds identified in propolis extract by gas chromatography-mass spectrometry [12]. However, a recent study showed that it contains more than 300 constituents. The biological activity is originated from effective substances such as flavonoids, terpenes, caffeic, ferulic, and coumaric acids and esters [13]. Figure 2 shows the chemical structure of the main bioactive compounds in propolis [14]. The antiseptic, anti-inflammatory, antioxidant, antibacterial, antimycotic, antifungal, antiulcer, anticancer, and immunomodulatory properties of propolis make it an important part of traditional medicine. Moreover, the free radical scavenging ability may consider an essential property of propolis for utilizing it in an encouraging manner [15].

There are diverse types of propolis owing to their color, geographic region, and extraction methods. The color of propolis changes from yellow to dark brown according to

✉ Mohamed El-Sakhawy
mm.el-sakhawy@nrc.sci.eg

[1] Cellulose & Paper Department, National Research Centre, 33 El Bohouth St, P.O. 12622, Dokki, Giza, Egypt

[2] Packing and Packaging Materials Department, National Research Centre, 33 El Bohouth St, P.O. 12622, Dokki, Giza, Egypt

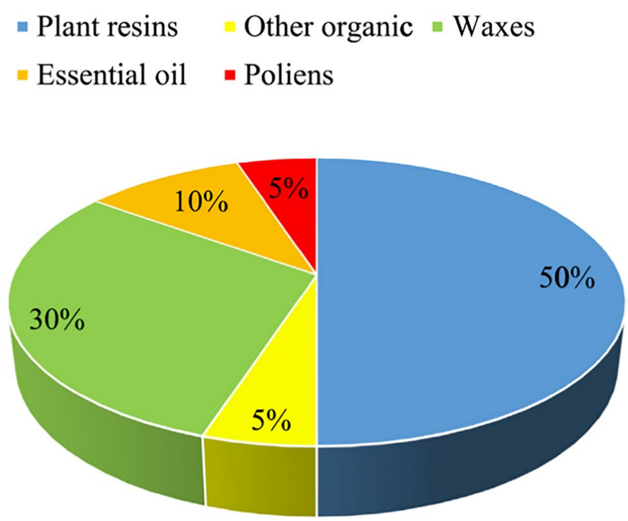

Fig. 1 Chemical composition of propolis [11]

the location, season, bee species, and available plants for bee feeding [16].

Regarding the food industry, there are a few relevant obstacles to the widespread use of propolis. One of the biggest obstacles is propolis's characteristic taste and flavor, which adversely affects the product's sensory qualities. Because raw propolis contains high contaminants and is poorly soluble in water, raw propolis cannot be used directly in food products. Propolis must be extracted with solvents to increase the concentration of active ingredients [17]. The aim and the novelty of this review are to shed light and clarify the importance of propolis and how to use it as an additive to foodstuffs without affecting the properties and taste of the product.

2 Food packaging overview

Microbial contamination in food is primarily caused by collecting, shipping, and packaging. Many pathogenic bacteria are found on plants, including *Escherichia coli* and *Staphylococcus aureus*. As they are stored, they are susceptible to spoilage, resulting in fungi growth. Such products can be contaminated if they are not adequately cleaned or processed before consumption. Searching for bioactive materials will keep vegetables against the growth of pathogens and the spoilage caused by fungi [18]. The losses in the postharvest industry result from fungi that contaminate fruit and grow disease. Various fungicides are used to control postharvest fungi, such as inorganic substances and artificial chemicals. New alternatives should be explored to meet the increasing requirement for safe and nutritious food [19].

As a protective layer formed on food surfaces, edible coatings are thin sheets of organic materials such as proteins and polysaccharides. Utilizing natural extracts for food protection has received growing interest in constructing effective edible coatings as an appropriate substitute to reduce fungal pathogens in fruits during postharvest shelf life [20]. Propolis, a natural and safe compound, was investigated for food preservation due to its antimicrobial and antioxidant activities [21]. Propolis was being used as a natural additive in dairy beverages and fruit juices [22]. A review also described the antibacterial effect on other foods such as

Table 1 Compounds identified in propolis extract by gas chromatography-mass spectrometry

RT (min)	KI	Identification	RA (%)	Class
8.011	1157	Catechol (1)	6.27	Polyphenol
10.347	1365	(Z)-2.6.10-trimethyl-1.5.9-undecatriene (2)	1.98	Unsaturated hydrocarbon
15.563	1832	E.Z-farnesol (3)	2.35	Sesquiterpene
17.21	2002	Hexadecanoic acid (4)	0.67	Unsaturated acid
17.53	2036	Ethyl palmitate (5)	0.35	Ester
22.772	2585	Medicarpin (6)	6.43	Flavonoid
23.885	2697	7.4′-dimethoxy-2′hydroxy-isoflavone (7)	4.34	Flavonoid
24.5	2758	(3S) vestitol (8)	16.5	Flavonoid
24.667	2775	(3S) isovestitol (9)	6.73	Flavonoid
24.745	2782	2H-1-benzopyran-7-ol (10)	0.8	Benzopyran
25.151	2822	Formononetine (11)	1.33	Flavonoid
32.262	3395	Dotriacontan-1-ol (12)	4.58	Saturated alcohol
34.001	3490	Amirine (13)	23.29	Triterpene
35.108	3538	Cycloartenol (14)	1.21	Triterpene
35.259	3543	Lupeol (15)	2.91	Triterpene
38.129	3614	Lupeol acetate (16)	20.26	Triterpene

RT, retention time (minutes); *KI*, calculated Kovats index. Relative area (%): corresponds to the relative area of the identified metabolites [12]. (License Number 5446950448713, 13/12/2022, Elsevier)

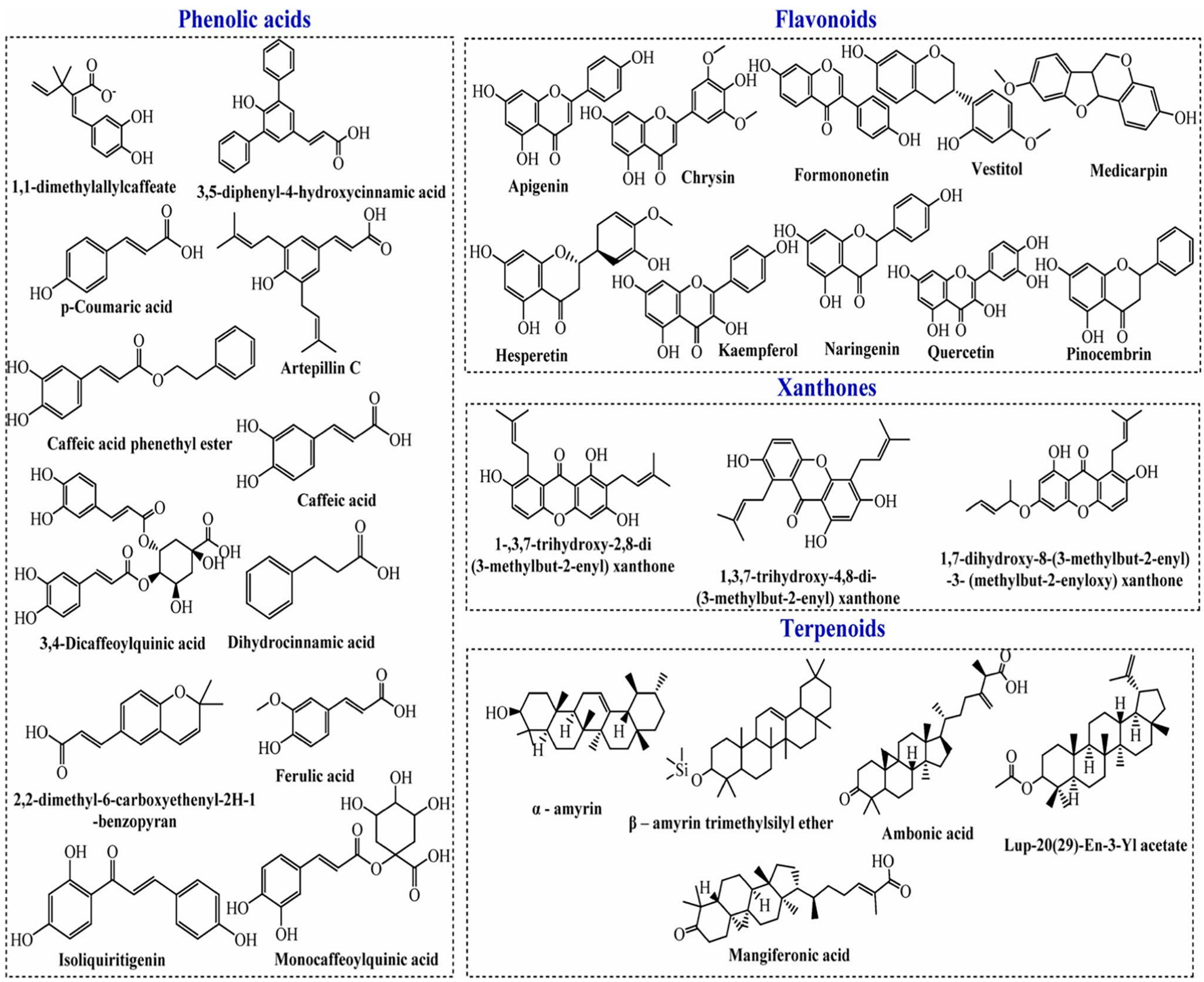

Fig. 2 Chemical structures of propolis bioactive compounds [14]. License Number 5446960510218, 13/12/2022, Elsevier

vegetables, fruits, eggs, and meat by Bankova et al. [23]. A growing interest in employing propolis for packaging methods planned to keep products fresh and optimize their shelf life has increased [24].

Propolis, which has been successfully employed mainly in the pharmaceutical business, was chosen as the active component for producing natural packaging materials [8, 25]. Coating techniques were employed to place active layers on plastic films and cellulose sheets to accomplish this goal. This technique showed the polyphenols' gradual breakdown over time consequently extending the stability of the generated active coatings.

Biodegradable active polysaccharides are a promising green strategy for reducing widespread worries about environmental pollution and human health issues that evolved from using plastics [26–29]. For example, the creation of active films based on chitosan, made from discarded crayfish shells enhanced with bioactive extract (5–20%) of propolis, showed promising capabilities for food packaging applications. The results established that adding PS improved the films' thermal stability and mechanical characteristics, such as their yield strength, stress at break, and tensile modulus. Moreover, it improved antibacterial and antioxidant functions. Overall, CS-based composite films appear to be a viable environmentally benign replacement for petroleum-based synthetic polymers, allowing food goods to have longer shelf lives due to their eco-friendliness [30]. Moreover, the addition of 10% ethanolic extract of propolis and 33% chitosan nanoparticles into edible film formulations provides pertinent information on edible propolis-chitosan nanoparticle films for strawberry preservation. Consequently, using these films in packaging applications in the future holds promise for extending the shelf life of food goods [31].

Mustafa, et al. prepared biodegradable active and intelligent films that would later be applied to food packaging. The results showed that increased PE content was associated with high anti-bacterial activity. The bacterial attack retaliation at higher PE concentrations and a color-change reaction were also seen in food rotting tests. The prepared films were examined on pasteurized milk to regulate their potential applicability. Both an anti-bacterial response and color change were evaluated to prevent and detect food spoiling using an active and intelligent food packaging system [32]. In the field of chicken kebabs preservation, propolis aqueous extract can inhibit the growth of bacteria in marinated chicken breast for 12 days at 5° C. The samples' shelf life was dramatically increased to 6 days by the addition of the propolis extract. The rise in pH and TVN might be controlled by propolis extract. The sensory characteristics of pre-cooked kebab chickens were also improved by using propolis aqueous extract; as a result, the odor alterations in the propolis extract-containing samples happened more gradually than in the control samples. Adding propolis extract up to 8% v/w had no discernible detrimental effects on the color and general acceptance of the samples. The propolis extract significantly improved the textural parameters of marinated chicken breast. These results showed that it is feasible to substitute chemical preservatives in ready-to-cook poultry products without compromising the goods' quality or shelf life or their appeal to consumers [33].

Khodayari, M. et al. added propolis ethanolic extract and *Tanacetum balsamita* essential oil to poly(lactic acid)/cellulose nanocrystal polymer sheets before being cast in a solvent. These films showed high antibacterial efficacies and long shelf life of cooked sausages by 50 days when kept in the refrigerator [34].

Due to its unique qualities, such as film-forming, barrier property, and antibacterial activity, propolis extract conjugated with chitosan in edible coating formulation could be employed as a food-grade composite for coating eggs. In addition, the formulation can maintain albumen quality, store HU at a high level, prevent pH from rising, stop water and weight loss, boost eggshell thickness and strength, and reduce microbial contamination [35].

Edible films based on natural cassava starch, beeswax, and ethanolic propolis extract were created effectively. Starch was added to produce larger thickness and water vapor permeability values. Beeswax and ethanolic propolis extract were added to natural cassava starch to adjust the microstructural in the starch molecules. When compared to edible films made using a different lipid source, obtained edible films had lower values for water vapor permeability and water solubility and were more soluble in acidic than alkaline solutions. The moisture content and vapor water permeability decrease with increasing beeswax concentration, which is crucial for applying edible films and coatings on fruits and vegetables. The addition of propolis to native films made of cassava starch showed antibacterial efficacy against *Aspergillus niger*, but it also diminished the films' lightness, making them opaque and yellow-colored [36].

3 Propolis applications in food packaging

3.1 Films

Perishable foods, including meat, dairy products, and cooked leftovers, can benefit from adding chitosan to the packaging as an effective antimicrobial reagent for preserving the quality and extending the shelf life [37]. With its high polyphenol content and wide range of biological actions, propolis can be integrated into films as an effective reagent. Chitosan films containing various ratios of propolis extract were established. Additionally, combining chitosan and propolis decreases the water vapor/oxygen permeability index, which enhances the potential for using chitosan-based propolis sheets as effective ingredients for food packaging [38].

The antimicrobial efficiency of chitosan-coated polypropylene blends alone and incorporated with ethanolic extract of propolis was assessed against various foodborne pathogens. The chitosan-treated film demonstrated a distinct spectrum of antibacterial action. Incorporating polypropylene into the coating at 10% (propolis resin/chitosan) improved antimicrobial action against all pathogens examined. The results propose that coating chitosan onto the food-contact surface of synthetic polymer films' is a viable approach for producing antimicrobial packaging substance. Furthermore, the antimicrobial properties of propolis make it the ideal biomaterial for coatings and blends based on biopolymers [39].

By using chitosan, including propolis-ethanolic extract, as a coating biopolymer, fruit quality losses were minimized. In contrast to the control papayas, a decreased deterioration index and infection width were found, which resulted in a 2-day increase in shelf life [40]. Furthermore, in using propolis extract as a component for food preservation, a linear relationship between the zone of cellular growth inhibition and concentration was observed [39]. Table 2 summarizes some recent studied concerning packaging films with propolis additives.

3.2 Active and intelligent packaging

As part of the active packaging system, the food should be able to interact with it, for example, by releasing effective substances that afford protection against microbial spoilage. Propolis can be fully utilized to accomplish a long shelf life by utilizing its antimicrobial and antioxidant properties. During the paper production process, a large amount of active and free water molecules are generated

Table 2 Packaging films with propolis additives

Polymer matrix	Propolis type and conc	Propolis benefits	Applications	References
Active pullulan films	Propolis ethanol extract, 3, 5, or 10%	The antifungal activity increased significantly, improved UV radiation protection	Natural active packaging to protect food against fungi	[41]
Cassava starch, poly(butylene adipate-co-terephthalate)	Brazilian propolis by-product, 4%	Flexible film with promising mechanical properties and excellent antioxidant and antibacterial	Sustainable alternative for plastic as biodegradable packaging	[42]
Pectin films	Water-soluble propolis extract, (1, 2, or 3%)	Significant barrier to UV light, exceeded 50% transmittance, increased the antioxidant activity of the films	Active films, packaging for food preservation	[43]
Carboxy-methyl cellulose	Ethanolic propolis extract, 3%	Inhibiting microbial growth, preventing lipid oxidation, and keeping the quality and extends the shelf life of chicken breast meat stored at 2 °C for 16 days	A composite edible active packaging coating as natural substitute to synthetic preservatives applicable for several food types	[44]
Corn starch films, *Thymus vulgaris* essential oils	Ethanolic extract of propolis, 10% (w/w)	Enhanced the elasticity of the films, antibacterial effect against *E. coli*	Potential application in antibacterial food packaging films	[45]
Polylactide-based films (PLA), poly(ethylene glycol)	Chloroformic propolis extract, 5–20% to PLA	Increases the water vapor resistance, extending the shelf life of the blueberries packed in the novel films, maintain the firmness of the fruit for a longer time	Extend the shelf life of stored food products	[46]
Sodium alginate, nano-SiO_2	Green propolis extract, (3% w/w based on SA mass)	Increased tensile strength, UV protection, radical-scavenging activity, antioxidant activity, and improved the light barrier of sodium alginate films	Active food packaging films	[47]
Chitosan from waste crayfish shells	Propolis extracts (5–20%)	Enhanced the films thermal, mechanical, and biological properties and extends their shelf life. Besides, it improved the antioxidant and antimicrobial activities	Packaging oxidation-sensitive food products instead of synthetic plastics	[30]

by incorporating propolis extract into the matrix to the system's equilibrium [48].

Active and intelligent food packaging films were developed based on polyvinyl alcohol and starch, as biodegradable polymers, incorporated with natural propolis extract additives (PE) up to 20% and anthocyanin from rosemary extract using boric acid as a cross-linker. The results proved the compatibility of films mixture with high mechanical strength and anti-bacterial activity. Films responded visibly by changing color and protected milk from spoilage [49]. Cellulose-based packaging materials, which contain additional chitosan/propolis complex, have exciting capabilities for the food packaging sector. The blends of cellulose/chitosan/propolis have been achieved in providing enough active polyphenols in paper production which release in contact with moist food to develop an antimicrobial action. The blending of propolis and chitosan improves the antimicrobial and antioxidant capacity paper and cellulosic packaging sectors [50, 51].

Food packaging research and innovation have focused on incorporating bioactive substances and ingredients. The use of bio-based packaging substances with antioxidant and antimicrobial properties is becoming increasingly popular since oxidation and contamination caused by microorganisms are the main concerns for food safety and quality [52]. As a promising biodegradable, effective food package, propolis shows excellent potential. In addition to being a valuable supplier of polyphenols with various biological activities, propolis is an effective active agent that can be used in film [38].

Promising trials have been carried out to improve the release of active materials at rates appropriate for a wide range of food packaging applications. Incorporating propolis into polylactic acid sheets controlled by polyethylene glycol and calcium bentonite was adjusted through the casting technique. In this case, the delivery system would be a very efficient way of delivering the active agents because some polyphenol acids would be released into the food. Other flavonoids, in contrast, stay in the polymer to become active at the food-polymer interface. The incorporation of propolis in the biopolymer may present a probable delivery method for food packaging sectors. Antimicrobial packaging contains additives that release gradually into the food to avoid microbial growth. As a result of their incorporation into the packaging materials, they are protected from oxidation or degradation reactions and remain active for the lifetime of the food item [53]. Incorporating propolis and yerba mate extracts into carrageenan-starch blends establishes a practical approach for improving new influential films with antioxidant properties. Food products can be preserved by preparing biopolymeric matrices that deliver bioactive compounds [54].

Promising composite materials consisting of cellulose nanocrystals (CNC) and polylactic acid were produced by combining *Tanacetum balsamita* essential oil and propolis ethanolic extract through a solvent casting technique. The antimicrobial effectiveness of the composite extends the shelf life of vacuum-packed cooked sausages to 50 days of refrigerated storage. Furthermore, the results showed that the formed composite materials with antimicrobial reagents such as propolis and essential oils might be a good platform for developing biodegradable packaging [34].

Active gelatin films were loaded with propolis extract in combination with clove and/or basil essential oil. By combining these components in gelatin, the content of total phenols was increased, a radical-sequestering function was enhanced, and antimicrobial properties were enhanced. The addition of these components in the gelatin matrix increased the content of total phenols and the sequestering activity of radicals and antimicrobial activity. These results indicate that these films may be suitable for food preservation with low moisture percentage and sensitivity to lipid oxidation. In addition, as a result of adding essential oil, the optical and UV/visible light barrier properties were improved, which may lead to better protection against lipid oxidation [55].

Polylactic acid films containing different contents from propolis extract, as an active agent, showed antioxidant effect on dry meat sausage. These films offer active packaging that may extend meat products' shelf life [56].

3.3 Coatings

3.3.1 Edible coatings

Food packaging often uses edible coatings as they are economical and environmentally friendly. These coatings consist of thin films of hydrophilic and hydrophobic materials, such as polysaccharides (e.g., sodium alginate) and proteins (e.g., sodium caseinate), and non-polar materials (e.g., vegetable oils and resins), that can be applied to a wide variety of foods, fruits, and vegetables [57].

In addition to preserving food, edible coatings improve the flavor and texture of meat products. Due to their acceptable influences, it is possible to use these biopolymers as the main ingredient for the next generation of packaging. For example, edible coatings based on gelatin containing propolis were established and utilized for raspberries to prolong their shelf life. The presence of propolis extracts altered the mechanical property of the films to become more flexible edible sheets but still colored with lower transparency. In addition, the tested fungus was significantly inhibited by the active films [57].

The impact of dipping poultry meat in a propolis and chitosan coating supplemented with *Zataria multiflora* essential oil was assessed. The chitosan enriched with propolis and

Zataria multiflora essential oil showed a great antibacterial and antioxidant influence against some bacteria and may improve the chemical and organoleptic properties. This combination was suggested as an active packaging material because it extends the shelf life of chicken breast meat to more than 2 weeks. Various trials have been carried out to evaluate the synergistic antimicrobial and antioxidant properties through mixing propolis and chitosan against food spoilage microorganisms and lipid oxidation [58, 59].

The natural antioxidant and antibacterial properties of chitosan and propolis may effectively extend the shelf life of *Nemipterus japonicus*. For example, chitosan containing propolis delayed the growth of total bacteria and decreased refrigerated fillets' deterioration. In addition, chitosan combined with propolis may successfully reduce lipid oxidation and protein decomposition. Chitosan and propolis as antioxidants and antibacterials were presented as promising materials for maintaining the storage quality of *Nemipterus japonicus* and expanding its shelf life [58]. The chitosan coating with propolis improves food's microbial, chemical, and sensory quality, enhances shelf life, and maintains its quality through synergistic effects [37].

The edible coating has been reported as a promising technique for fruit or vegetable protection, enhancing its shelf life, keeping the product against pathogens, and hindering spoilage. The incorporation of nanoparticles into edible coatings improves their mechanical and antimicrobial properties and consequently improves the shelf life of food [60]. Moreover, incorporating propolis into chitosan coatings enhanced the protection of fresh-cut broccoli [31].

Edible films based on hydroxypropyl methyl cellulose with different concentrations of propolis were evaluated. The incorporation of propolis improves the water vapor permeability and gives rise to more rigid, less flexible, deformable, and colored films with reduced gloss and transparency. The formed composites showed a distinguished antifungal property and a superior inhibition of *A. niger*. The properties of hydroxypropyl methyl cellulose films containing propolis improved the water barrier properties. Moreover, the presence of propolis maintained the antifungal activity of this bioreagent; as a result, it may be applied to regulate the fungal degeneration in foodstuffs [10].

There is a strong odor and unpleasant taste to propolis, and consequently, its encapsulation in edible films for food preservation can regard as another way of its consumption. Edible coatings based on hydroxypropyl methyl cellulose containing propolis were established and applied to inhibit weight loss and browning of muscatel table grapes. Moreover, these coatings improve gloss and microbial safety and control the growth in oxygen utilization through cold storage. In addition, propolis incorporation enhanced the grapes' color luminosity [8].

Cassava starch, beeswax, and propolis-based edible films showed lower water vapor permeability than films made with another lipid source. The amount of beeswax and moisture content decrease when the beeswax concentration increases, which is essential for utilizing edible films and coatings on fruits and vegetables. Although adding propolis to films exhibited antimicrobial activity against *A. niger*, it reduced their transparency, resulting in opaque and yellow-colored films [36].

Silver nanoparticles were made and conjugated to *Aloe vera* gel using propolis extract and microwave heating. Several bacterial and fungal strains were tested against the coating to determine its effectiveness as an antibacterial and antifungal. Food commodity packages can last longer by incorporating antimicrobial, edible coatings that have desirable barrier properties. It has been shown in several studies that rice by-products and propolis can be used for the preparation of edible coatings [61, 62].

3.3.2 Eggs coating

Despite their excellent protein content, eggs are a perishable product. Various methods can preserve food, including applying protein coatings combined with antimicrobial agents, such as propolis. An evaluation of the effect of rice protein coatings combined with propolis on the interior feature and eggshell breaking strength of fresh eggs through storage below 20 °C for a long time was conducted. By treating eggs with rice protein and propolis, the quality of eggs was preserved for a longer time than without treatment. At concentrations of 0, 5, and 10%, the propolis solution was added to the rice protein solution. Eggs have been successfully extended in shelf life using rice protein and propolis as coatings [61].

Propolis has been studied for its effects on egg weight loss, hatchability, chick performance, and reduction of the bacterial activity happening on eggshells. Results showed that propolis could be used as an alternative to chemical disinfectants for hatching eggs without adversely affecting quail chicks' hatchability and performance. Customers have considered propolis to be a safe alternative preservative agent. During storage, propolis-covered table eggs improved the interior egg quality. As a result of this study, propolis may render hatching eggs safe, non-toxic, and effective [63]. In addition, propolis extract protects the internal egg quality parameters when applied to shell surfaces [64].

Combining propolis extract with chitosan in an edible coating formulation can afford a food-grade composite with exceptional features such as film-forming, barrier properties, and antibacterial action, which could be used as a food-grade coating for eggs. An eggshell coated with chitosan-propolis extract may maintain albumen properties, avoid pH fluctuations, maintain weight and thickness, and reduce microbial contamination [35].

3.3.3 Fruits coating

Using chemical fungicides can be detrimental to human health and the environment, while they cannot provide physical protection. In long-term storage, physiological and biochemical losses and phytopathological agents result in significant fruit deterioration [57]. Many different agricultural products have the potential to be contaminated by *Aspergillus flavus*. Fruits are protected against humidity, oxygen, and solute transition by bio-coating. The bio-coating is intended to be consumed with fruit, so it needs to be made from natural materials, such as propolis. Results showed that fruit treated with 0.50% propolis was most promising. According to the study, 0.50% propolis inhibited ripening and increased biosynthesis of nutritional components such as total flavonoids and antioxidants. The quality of dragon fruit was significantly altered when treated with different amounts of propolis extract [65].

Nanoparticles of chitosan and propolis at a concentration of 40% showed significant inhibition on the spore germination and, mainly, on the aflatoxin creation of *A. flavus* [66]. By reducing weight loss, increasing fruit firmness, preventing fruit browning, and reducing decay incidence, biomaterials maintained postharvest quality in loquat fruit. If treated with 0.5% propolis extract, loquat fruits can be stored for 35 days without deterioration [67].

Using natural polymers as antimicrobial substances have been reported as promising method to reduce contamination [68]. A pullulan coating containing either 5 or 10% propolis was evaluated for its impact on cherry tomatoes during refrigerated storage. Mixing propolis with the pullulan coatings improved the antimicrobial properties and increased their activity while lowering cherry tomatoes' weight loss and maturation time. Microorganisms were diminished, and the ripening process was delayed owing to propolis; thus, the shelf life was extended. Tomatoes did not taste or smell differently after being coated in propolis while enhancing the skin's brightness, making coated cherry tomatoes more appropriate for inspectors [69].

The effect of propolis coating on tomato preservation and the best concentration to use were investigated by applying different concentrations of propolis extract to tomatoes. Applying 10% propolis as bio-coating decreased the rate of weight loss and preserved fruit firmness [70]. Egyptian propolis was evaluated to reduce tomato bacterial wilt produced by *Ralstonia solanacearum* under greenhouse and field conditions [71]. Moreover, propolis decreased the respiration rate of sweet cherry; decreased weight loss; delayed the decline of titratable acid, soluble solids, and fruit hardness; and slows the loss of fruit vitamin C. Propolis keeps cherry fruit fresh for a long time [72].

Propolis was evaluated as a bio-coat of the tangerine by dip process for a short time [57]. Wax inside propolis offers hydrophobic properties that allow propolis to be fixed on various surfaces, decrease direct contact of fruit with air, and control fruit's respiration and transpiration rate [73]. Propolis has been applied as a postharvest technique for the local tangerine cultivar Garut. According to physicochemical tests, propolis coating preserved fruit firmness, diameter, and vitamin C levels. In addition, propolis lowered decaying processes 20% longer than the control, with a 10% concentration being best for application [74].

4 Propolis applications in food and feed

4.1 Propolis encapsulation

Encapsulation technology can overcome the limits of environmental sensitivity and low solubility of bioactive substances. Moreover, encapsulation is an appropriate method to control the active substance into polymer chains and, thus, support a continuous release of the effective substances. The customers' suitability is reduced toward foods containing propolis as an ingredient because of its bitterness and astringency, which provide strong and unpleasant flavors [15]. As a result, the bitter taste of propolis that hinders its applications in the food area could be overcome [8]. Therefore, encapsulation of propolis has been reported as suggesting method for developing active delivery systems that can maintain propolis polyphenols active for an extended period. An encapsulation process effectively prevents the loss of natural active ingredients and keeps them stable until consumed [24].

The main benefit of propolis could be achieved from its extract. Therefore, alcoholic propolis extract has been investigated as a food additive. The encapsulation could be a practical approach to overcoming crude propolis problems. Sodium alginate was used to encapsulate the ethanol extract of propolis. Beads were examined in simulated gastric and intestinal solutions for release properties. The process of microencapsulation involves entrapping materials or compounds inside another so that they are immobilized, produced, and functionalized. Microparticles are made up of two parts, the core material, such as bioactive substances, like propolis, and the shell. One of the most essential features of microcapsules is their ability to release core materials at the right time and place. The encapsulation of ethanolic extract of propolis was planned to improve antifungal efficiency through film or coating growth. Zein is proposed as an encapsulating matrix to keep the ethanolic extract of propolis by utilizing the anti-solvent methodology [75].

Incorporating propolis extracts containing a high percentage of polyphenols into polymeric matrices will improve their stability and bioavailability. Also, this technique may reduce its strong odors and flavors [76]. Furthermore, the encapsulation may enhance the delivery techniques, presenting the prolonged and regulated release of food components. Propolis ethanol extract was encapsulated with biopolymers like gelatin, casein, and chitosan using different techniques. Moreover, the encapsulation properties of these methods are lower than 80%. Other techniques which apply particular circumstances like high temperature may be destructive for effective propolis substances. Ionic gelation, which is cheap and does not require toxic solvents, could be an alternative to encapsulate propolis ethanol extract without using toxic solvents and reach high encapsulation efficacy. This technique has microencapsulated the active substances of ethanol-based propolis extract with alginate matrices. The prepared capsules were presented as a promising method for consuming propolis in a powder form free of alcohol.

Moreover, the capsules will exhibit application in food manufacturing as food constituents. Alginate beads, a biopolymer used as food additives, have been created by the ionic gelation technique with slight alterations. Sodium alginate was mixed with propolis extract to form a homogeneous solution during this technique. As part of the preparation of propolis-alginate beads, the solution was injected into a calcium chloride solution through a syringe. The prepared propolis-alginate beads were dried for ethanol elimination to obtain consumable alcohol-free propolis capsules. The release profile showed that active propolis ingredients could achieve the upper part of the large intestine leading to a growth in the bioavailability of these components [76].

Alginate beads encapsulated jabuticaba peel, and propolis extracts were explored for preparing a novel natural colorant antioxidant additive. The ionotropic gelation conducted the alginate encapsulation by dripping into the calcium chloride solution. The authors demonstrated that encapsulation of anthocyanins (from jabuticaba) and phenolic compounds (from propolis extracts) were sustained onto alginate hydrogel beads. These results suggest the possible applications of these beads as an oral delivery system for supporting natural healthy food/beverage colorants additive [77]. In foods where it is incorporated, propolis can be encapsulated in nanoemulsions to reduce its effect on organoleptic properties. As a result, these systems promote the applications of bio-based materials as nutrients by decreasing their taste impact and improving their antimicrobial properties [78]. Furthermore, emulsions loaded with propolis extract have been utilized to increase their properties for various applications [15, 79, 80].

Dairy proteins were emulsified with polysaccharides to co-encapsulate and protect bioactive nutrients. For example, whey protein isolate/propolis/alginate beads were designed at pH 7.0 for stabilizing α-tocopherol–contained emulsions, the active component of vitamin E.

In a different technique, the propolis can be finely dispersed into polymeric nanoparticles and then sprayed with chitosan microspheres to form solid dispersion matrices to improve its solubility in an aqueous solution [81]. Microencapsulations of gum arabic and maltodextrin were also applied for propolis encapsulation. Approximately 92% of α-tocopherol and 72% of propolis were effectively encapsulated in sunflower oil drops stabilized by whey protein isolate/propolis/alginate matrices [82].

Polysaccharides have been investigated as a promising polymer for drug delivery applications [83–86]. A monopore filter device was used to design chitosan-containing propolis beads, which allow polyphenols to be encapsulated without being heated, shattered, or subjected to toxic solvents. In addition, as a natural antimicrobial delivery system, the beads could limit the expansion of pathogenic/spoilage bacteria in food products [24]. Table 3 demonstrates a valuable study concerning propolis encapsulation.

4.2 Spray-drying

Propolis extract has been spray-dried utilizing gum arabic and octenyl succinic anhydride starch as transporters. This method maintained the antioxidant action of propolis and permitted propolis production as a powder. In cold water, spray-dried propolis dispersed quickly and was stable throughout storage at room temperature. It also had low hygroscopicity and was highly stable. This method has increased the application of propolis in many modern applications, especially in the food sector. Recently, the increasing attention in some food industries to discover bio-additives has expanded the attempts to obtain bioactive substances from biomaterials and improved stable and valuable derivatives. Spray-drying has been presented as a promising technique that may decrease strong taste and aroma. Pharmaceutical and food industries use this method to keep products from environmental circumstances, increase product shelf life, and mask nasty flavors [24]. Spray-dryer was used for efficient propolis encapsulation to create a natural food ingredient with antioxidant activity. Figure 3 shows micrographs of propolis microcapsules [87].

4.3 Preserving food

The probable function of propolis as a food additive has yet to be established, but it has an unpleasant taste that can alter food texture and taste. The addition of 0.1% water extract of propolis on fresh Shibuta (*Barbus grypus*) fillets through frozen storage expanded the product's shelf life by around 1 week. In contrast, propolis's 0.5% water extract caused a considerable shelf life expansion of the Shibuta

Table 3 Encapsulation methods used in the protection of the propolis bioactive compounds [R2]. License Number 5446960510218, 13/12/2022, Elsevier

Geographic origin	Encapsulation method	Wall materials	Main goal of the study	Findings
Iran	Freeze-drying	Whey protein isolate	Encapsulate propolis extract to enhance protein's functionality and physicochemical properties	83.5–87.5% efficiency yield, 65.5–84.0 encapsulation efficiency. Propolis interacts with whey protein isolate via hydrophobic interactions
India	Vacuum drying	Maltodextrin	Encapsulate propolis and then determine the properties of microparticles	Increases in propolis extract concentration and pressure resulted in increased total phenolic content
Turkey	Spray and freeze-drying	Whey protein isolate, gelatin, maltodextrin, lactose, and gum arabic	Examine the effects of different coating materials and encapsulating methods on the characteristics of propolis powder	The encapsulation procedure had a significant impact on the characteristics of propolis powder, and encapsulation efficiency differed only slightly for both drying processes, with results exceeding 95%
Turkey	Ionic gelation method	Alginate	Investigate the release property of propolis-alginate microcapsules	The controlled release studies revealed that propolis bioactive components could reach the upper part of the large intestine
Brazil	Spray-drying	Gum arabic and maltodextrin	Obtain spray-dried powders from the green, brown, and red varieties of the Brazilian propolis	Artepillin C, luteolin, kaempferol, kaempferide, p-coumaric acid, caffeic acid, and chlorogenic acid were present in microparticles
Malaysia	Liposome	Soy phosphatidylcholine and cholesterol	Use thin film hydration to create stingless bee propolis in liposomes	Intermolecular hydrogen bonding and hydrophobic interactions between the propolis extract and the phospholipid membrane were responsible for the encapsulation of propolis extract in liposomes
Slovenia	Freeze-drying and spray-drying	Gum arabic, maltodextrin, and inulin	Encapsulate propolis extract using freeze-drying and spray-drying and gum arabic, maltodextrin, and inulin as coating materials	Freeze-drying is more effective than spray-drying in encapsulating propolis, and the encapsulated propolis powders were effective to extend the shelf life of omega-3 fatty acid-rich oil
China	Electrostatic deposition	Zein, caseinate, and alginate	Encapsulate and study the bioaccessibility of propolis via one-step assembly	86.5% encapsulation efficiency, 59.6 μg mg^{-1} loading capacity, and 80% bio-accessibility of propolis were reached by zein/caseinate/alginate NP
Turkey	Spray-drying	Maltodextrin and whey protein isolate	Study the impact of the spray-drying method on the physicochemical and structural properties of encapsulated propolis powder	The moisture content and water activity of products increased with increasing inlet air temperature and decreased output air temperature, resulting in encapsulation efficiency ranging from 29.79 to 99.73%
Brazil	Spray-drying	Concentrated pea protein (CPP)	Encapsulate propolis extract using concentrated pea protein as wall materials	Three formulations of (CPP) were tested (2, 4, and 6% weight: volume), and microparticles with 2% CPP showed the highest encapsulation efficiency
Brazil	Spray-drying	Rice, pea, soybean, and ovalbumin proteins	Encapsulate propolis extract and assess in vitro digestion studies using rice, pea, soybean, and ovalbumin proteins as wall material	Encapsulation efficiency was greater than 70%, and the antioxidant activity of propolis was maintained (88% for propolis extract and 73% for the microparticles)

fillets by around 2 weeks compared to the control sample. Therefore, the water extract of propolis was presented as an accepted preservative for fresh fish products [88]. Propolis extract was proposed as a natural preservative for food in a nanoemulsion, which prevents the degradation and masking of the propolis off-flavor. Despite thermal stress and centrifugation, the nanoemulsion retained all biological properties evaluated for free extracts [89]. According to several researchers, the minimal addition of propolis extract for acceptance sensory of food products is 0.50% [58].

The antimicrobial impact of propolis on foodborne yeasts and its procedure as a biological approach for preserving soft foods against microbial spoilage was examined. The study also highlights the ability of propolis extracts to discourage the growth of checked yeast. The extract of propolis can be used as an antifungal agent against spoiled fruit juice yeasts in small quantities [90].

The efficacy of propolis action for decreasing anthracnose growth on Kent mango fruit and comparing its efficacy to chitosan action was developed. Using propolis alone or in conjunction with other treatments can extend the shelf life of fresh fruits and vegetables [91].

Ethanolic extract of propolis actions at 4.5% preserved the quality of '*Hindi-Besennara*' mangos during shelf life and was proposed as a natural option to synthetic chemicals. The hydrophobic mixtures of propolis extracts can form a biodegradable semipermeable film on fruit surfaces that may reduce water loss and gas exchange in different products. Propolis has several characteristics that might account for the lower weight loss observed in propolis-treated fruit compared to controls when applied at medium and high rates [92].

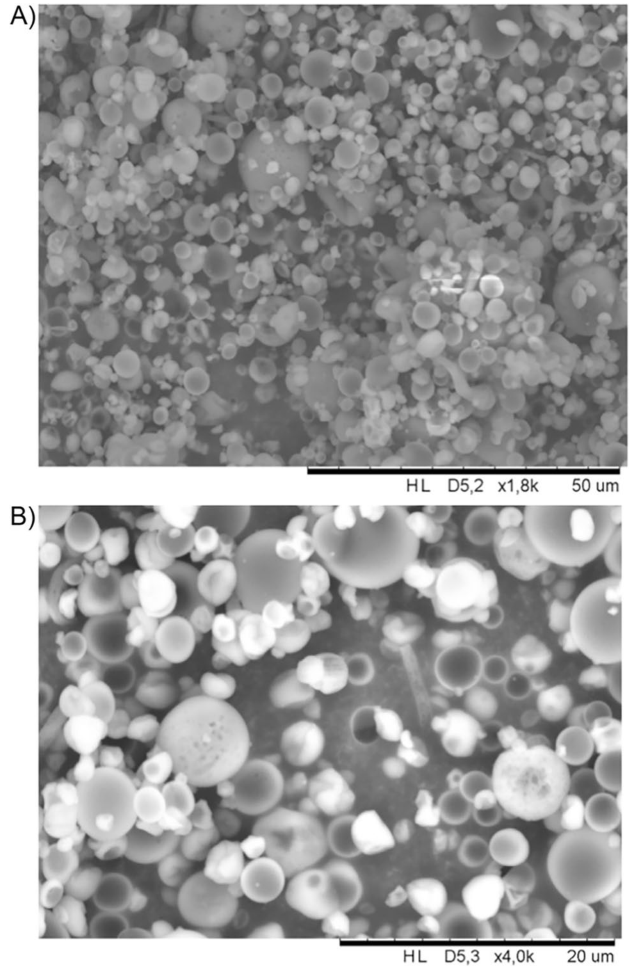

Fig. 3 Micrographs of propolis microcapsules. **A** magnified 1800×; **B** magnified 4000× [87]. License Number 5460740119380, 2/1/2023, Elsevier

4.4 Propolis as a food ingredient

Propolis has been used as a structuring agent to gel pomegranate seed oil, at a 5% concentration, as a limited replacement of the fat phase in chocolate spread [93]. Orange soft drinks flavored with propolis extract were made. Its antioxidant activity, microbiological stability, and color changes were assessed and compared to orangeade holding potassium sorbate. Soft drinks containing propolis extract displayed improved antioxidant activity and phenolic content compared to those including potassium sorbate. The authors suggested that the drinks holding propolis extract, as a bioactive reagent, can stay at a wide temperature range, for more than 16 weeks, without exhibiting quality and microbiological deterioration [94].

Fish sausage is a ready-to-eat/ready-to-cook material made from chopped fish meat. Fish meat is minced and combined with additives, then stuffed into casings, and fried. Using propolis extract to improve the quality of smoked carp (*Cyprinus carpio*) sausages stored for 9 weeks was studied. Propolis extracts added to carp sausages for 9 weeks significantly decreased the total aerobic mesophilic and psychrophilic bacteria counts compared to control samples. No mold or yeast was identified in any fish sausages during the entire storage period. Aqueous propolis extract positively influenced smoked carp sausage's chemical and microbiological properties after 9 weeks in the refrigerator [95].

The preparation and description of unique useful nanostructured lipid carriers (NLCs), including β sitosterol, were considered. Transmission electron microscopy results demonstrated spherical particles ranging around 100 nm, proving the probability of these formulations generating valuable foods. In addition, the formation of stable NLCs with long-term physical and oxidative storage stability has been demonstrated utilizing propolis wax and pomegranate seed oil as solid lipid and liquid lipid matrix [6]. Table 4 demonstrates some more recent studies concerning application of propolis as a food ingredient.

4.5 Propolis as a feed ingredient

The total antioxidant capacity and physicochemical properties of meat were assessed next to adding various amounts of propolis in broiler chickens' diets. Propolis in the chickens' diet can reduce oxidative compounds without changing their physical and chemical properties [100]. A variety of bio-products are being used in the dietary supplementation of vitamins, fatty acids, carotenoids, immunostimulants, hormones, and adjuvants, with propolis standing out. The use of propolis as a dietary supplement has been recognized in various animal products [101]. Propolis was added to the diets to increase the production performance of different fish types. Propolis is thought to have antimicrobial and antioxidant properties that enhance intestinal health, digestion, absorption, and growth.

Moreover, various minerals and vitamins in the propolis improve digestive cofactors and enzyme activity, enhancing absorption and digestion of nutrients with a subsequent increase in fish weight. Propolis enhances the growing operation and food absorption, decreases microbial activity, and develops the immune response and disease resistance of several grown fish variety. As a result, the water, ethanolic extract, and crude propolis are reported as bio-additives utilized in a low-dose manner.

Fish become healthier and more productive when propolis is applied, giving an excellent ability for utilization in aquaculture production. Lastly, fish consumption may have health benefits [101].

5 Future perspectives, challenges, and limitations

Since propolis is a natural, renewable, and safe product, expanding its use in the future is inevitable and necessary. Therefore, a prosperous and promising future for propolis applications in packaging and food is expected, especially after the many research that allowed and recommended its use. However, the expansion of its use as a food additive is hindered by its bitter taste, which allows it to be used only in small proportions. This problem could be overcome with modern research that starts to provide propolis in an acceptable form of encapsulated product or composites to overcome the unpalatable taste and smell.

6 Conclusion

Propolis has excellent potential for extending the shelf life and improving the quality of several food products. Propolis can prevent negative changes in food's physical and

Table 4 Propolis as a food ingredient

Polymer matrix	Propolis type and conc	Propolis benefits	Applications	Ref
Almond gum-sodium caseinate	Encapsulated propolis alcoholic extract (10–50% (w/w) based on the total solids content)	Higher thermal stability, improved antibacterial activity and lower cytotoxicity	Broaden propolis application in the food formulation and pharmaceutical industry	[96]
Edible coatings chitosan	Green propolis extract, 0.75–2.5% in coating solution either in active packaging or by immersion	Microbial reduction, antioxidant action	Conservation of pork cuts, increased the shelf life of pork chops by at least 12 d compared to the control samples	[97]
Potassium sorbate, 0.1% w/w	Ethanol extract, 0.4% and water extract 0.6% (w/w)	Lowered produced thiobarbituric values after 1 month of cured pork sausages storage	The preservation of meat products and to control microbiological spoilage	[98]
–	Propolis extracts, 0.25–1%	Preventing lipid oxidation, reduced total heterocyclic aromatic amines levels, prooxidant and antioxidant effects	Inhibition of harmful heterocyclic aromatic amines levels formed in cooked or fried meat products	[99]

chemical characteristics to keep food quality. However, the challenges that limit the widespread use of propolis as a food additive are represented in its unpalatable bitter taste and flavor, which negatively affects the food's sensory qualities, texture, taste, and flavor. As a result, more interest has been paid to using propolis extracts on a product surface or in the form of edible films containing propolis. The incorporation of propolis into polysaccharide-based films enhanced their water vapor barrier and antifungal properties. As a biodegradable packaging material, it can protect the quality of food products, mainly minimally processed fruits and vegetables. Because it contains many bioactive ingredients, propolis has a significant potential to extend the shelf life of a wide range of food products. In addition to being a preservative, it can also be used to prevent adverse physical and chemical changes. As a result of its antioxidant and antimicrobial properties, propolis extract delayed the oxidation and growth of lipids in aqueous smoked carp sausage. Propolis wax could be a novel ingredient in the formulation of lipid nanoparticles. By combining propolis with essential oils, the content of total phenols was increased, and the radical-sequestering function was enhanced; as a result, the antimicrobial properties were enhanced as well. The addition of propolis enhanced the water vapor barrier and antifungal activity of polysaccharides-based film, which can be helpful as a biodegradable packaging material to maintain the quality of food products, particularly for coatings fruits and vegetables.

Author contribution All the authors contributed to the data collection. The first draft of the manuscript was written by A. Salama, M. El-Sakhawy, and Salah A. A. Mohamed. All the authors read and approved the final manuscript.

Funding Open access funding provided by The Science, Technology & Innovation Funding Authority (STDF) in cooperation with The Egyptian Knowledge Bank (EKB).

Data availability This declaration is "not applicable"; it is a review article.

Declarations

Ethical approval This declaration is not applicable.

Competing interests The authors declare no competing interests.

References

1. Salama A, Etri S, Mohamed SAA, El-Sakhawy M (2018) Carboxymethyl cellulose prepared from mesquite tree: new source for promising nanocomposite materials. Carbohydr Polym 189:138–144. https://doi.org/10.1016/j.carbpol.2018.02.016
2. Hassan H, Salama A, El-ziaty AK, El-sakhawy M (2019) New chitosan/silica/zinc oxide nanocomposite as adsorbent for dye removal. Int J Biol Macromol 131:520–526. https://doi.org/10.1016/j.ijbiomac.2019.03.087
3. El-Sakhawy M, Salama A, El-ziaty AK, Hassan H (2020) Preparation and adsorption properties of chitosan/silica/Fe3O4 nanocomposite. Cellul Chem Technol 54:601–608
4. Bankova V, Popova M, Trusheva B (2018) The phytochemistry of the honeybee. Phytochemistry 155:1–11. https://doi.org/10.1016/j.phytochem.2018.07.007
5. Rojczyk E, Klama-bary A, Wojciech Ł (2020) Historical and modern research on propolis and its application in wound healing and other fields of medicine and contributions by Polish studies. J Ethnopharmacol 262:. https://doi.org/10.1016/j.jep.2020.113159
6. Soleimanian Y, Goli SAH, Varshosaz J, Maestrelli F (2018) Propolis wax nanostructured lipid carrier for delivery of β sitosterol: effect of formulation variables on physicochemical properties. Food Chem 260:97–105. https://doi.org/10.1016/j.foodchem.2018.03.145
7. Varvara S, Bostan R, Bobis O et al (2017) Propolis as a green corrosion inhibitor for bronze in weakly acidic solution. Appl Surf Sci 426:1100–1112. https://doi.org/10.1016/j.apsusc.2017.07.230
8. Pastor C, Sánchez-González L, Marcilla A et al (2011) Quality and safety of table grapes coated with hydroxypropylmethylcellulose edible coatings containing propolis extract. Postharvest Biol Technol 60:64–70. https://doi.org/10.1016/j.postharvbio.2010.11.003
9. Ghisalberti EL (1979) Propolis: a review. Bee World 60:59–84. https://doi.org/10.1080/0005772X.1979.11097738
10. Pastor C, Sánchez-González L, Cháfer M et al (2010) Physical and antifungal properties of hydroxypropylmethylcellulose based films containing propolis as affected by moisture content. Carbohydr Polym 82:1174–1183. https://doi.org/10.1016/j.carbpol.2010.06.051
11. Przybyłek I, Karpiński TM (2019) Antibacterial properties of propolis. Molecules 24:2047. https://doi.org/10.3390/molecules24112047
12. Mafra JF, de Santana TS, Cruz AIC et al (2022) Influence of red propolis on the physicochemical, microbiological and sensory characteristics of tilapia (Oreochromis niloticus) salami. Food Chem 394:133502. https://doi.org/10.1016/j.foodchem.2022.133502
13. Matin G, Kargar N, Buyukisik HB (2016) Bio-monitoring of cadmium, lead, arsenic and mercury in industrial districts of Izmir, Turkey by using honey bees, propolis and pine tree leaves. Ecol Eng 90:331–335. https://doi.org/10.1016/j.ecoleng.2016.01.035
14. Tavares L, Smaoui S, Lima PS et al (2022) Propolis: encapsulation and application in the food and pharmaceutical industries. Trends Food Sci Technol 127:169–180. https://doi.org/10.1016/j.tifs.2022.06.003
15. Brandão J, Bautista-silva JP, Roquete T et al (2019) Development of propolis nanoemulsion with antioxidant and antimicrobial

activity for use as a potential natural preservative. Food Chem 287:61–67. https://doi.org/10.1016/j.foodchem.2019.02.078
16. Salama A, El-Sakhawy M (2022) Polysaccharides/propolis composite as promising materials with biomedical and packaging applications: a review. Biomass Convers Biorefinery. https://doi.org/10.1007/s13399-022-02814-5
17. Pobiega K, Kra K (2019) Trends in food science & technology application of propolis in antimicrobial and antioxidative protection of food quality – a review. 83:53–62. https://doi.org/10.1016/j.tifs.2018.11.007
18. Pobiega K, Kraśniewska K, Derewiaka D, Gniewosz M (2019) Comparison of the antimicrobial activity of propolis extracts obtained by means of various extraction methods. J Food Sci Technol 56:5386–5395. https://doi.org/10.1007/s13197-019-04009-9
19. Hyldgaard M, Mygind T, Meyer RL (2012) Essential oils in food preservation: mode of action, synergies, and interactions with food matrix components. Front Microbiol 3:. https://doi.org/10.3389/fmicb.2012.00012
20. Cos P, Vlietinck AJ, Vanden BD, Maes L (2006) Anti-infective potential of natural products: how to develop a stronger in vitro 'proof-of-concept.' J Ethnopharmacol 106:290–302. https://doi.org/10.1016/j.jep.2006.04.003
21. Tosi EA, Ré E, Ortega ME, Cazzoli AF (2007) Food preservative based on propolis: Bacteriostatic activity of propolis polyphenols and flavonoids upon Escherichia coli. Food Chem 104:1025–1029. https://doi.org/10.1016/j.foodchem.2007.01.011
22. Thamnopoulos I-AI, Michailidis GF, Fletouris DJ et al (2018) Inhibitory activity of propolis against Listeria monocytogenes in milk stored under refrigeration. Food Microbiol 73:168–176. https://doi.org/10.1016/j.fm.2018.01.021
23. Bankova V, Popova M, Trusheva B (2016) New emerging fields of application of propolis. Maced J Chem Chem Eng 35:1. https://doi.org/10.20450/mjcce.2016.864
24. Mascheroni E, Figoli A, Musatti A et al (2014) An alternative encapsulation approach for production of active chitosan – propolis beads. Int J Food Sci Technol 49:1401–1407. https://doi.org/10.1111/ijfs.12442
25. Guo X, Chen B, Luo L et al (2011) Chemical compositions and antioxidant activities of water extracts of Chinese propolis. J Agric Food Chem 59:12610–12616. https://doi.org/10.1021/jf202818p
26. Salama A, Hesemann P (2020) Recent trends in elaboration, processing, and derivatization of cellulosic materials using ionic liquids. ACS Sustain Chem Eng 8:17893–17907. https://doi.org/10.1021/acssuschemeng.0c06913
27. Salama A (2016) Functionalized hybrid materials assisted organic dyes removal from aqueous solutions. Environ Nanotechnology, Monit Manag 6:159–163. https://doi.org/10.1016/j.enmm.2016.10.003
28. Salama A, Shukry N, El-gendy A, El-sakhawy M (2017) Bioactive cellulose grafted soy protein isolate towards biomimetic calcium phosphate mineralization. Ind Crop Prod 95:170–174. https://doi.org/10.1016/j.indcrop.2016.10.019
29. Salama A, Shukry N, El-Sakhawy M (2015) Carboxymethyl cellulose-g-poly(2-(dimethylamino) ethyl methacrylate) hydrogel as adsorbent for dye removal. Int J Biol Macromol 73:72–75. https://doi.org/10.1016/j.ijbiomac.2014.11.002
30. De Carli C, Aylanc V, Mouffok KM et al (2022) Production of chitosan-based biodegradable active films using bio-waste enriched with polyphenol propolis extract envisaging food packaging applications. Int J Biol Macromol 213:486–497. https://doi.org/10.1016/j.ijbiomac.2022.05.155
31. Correa-Pacheco ZN, Bautista-Baños S, de Ramos-García ML et al (2019) Physicochemical characterization and antimicrobial activity of edible propolis-chitosan nanoparticle films. Prog Org Coatings 137:105326. https://doi.org/10.1016/j.porgcoat.2019.105326
32. Mustafa P, Niazi MBK, Jahan Z et al (2021) Improving functional properties of PVA/starch-based films as active and intelligent food packaging by incorporating propolis and anthocyanin. Polym Polym Compos 29:1472–1484. https://doi.org/10.1177/0967391120973503
33. Mahdavi-Roshan M, Gheibi S, Pourfarzad A (2022) Effect of propolis extract as a natural preservative on quality and shelf life of marinated chicken breast (chicken Kebab). LWT 155:112942. https://doi.org/10.1016/j.lwt.2021.112942
34. Khodayari M, Basti AA, Khanjari A et al (2019) Effect of poly(lactic acid) films incorporated with different concentrations of Tanacetum balsamita essential oil, propolis ethanolic extract and cellulose nanocrystals on shelf life extension of vacuum-packed cooked sausages. Food Packag Shelf Life 19:200–209. https://doi.org/10.1016/j.fpsl.2018.11.009
35. Ezazi A, Javadi A, Jafarizadeh-Malmiri H, Mirzaei H (2021) Development of a chitosan-propolis extract edible coating formulation based on physico-chemical attributes of hens' eggs: optimization and characteristics edible coating of egg using chitosan and propolis. Food Biosci 40:100894. https://doi.org/10.1016/j.fbio.2021.100894
36. Pérez-Vergara LD, Cifuentes MT, Franco AP et al (2020) Development and characterization of edible films based on native cassava starch, beeswax, and propolis. NFS J 21:39–49. https://doi.org/10.1016/j.nfs.2020.09.002
37. Jonaidi Jafari N, Kargozari M, Ranjbar R et al (2018) The effect of chitosan coating incorporated with ethanolic extract of propolis on the quality of refrigerated chicken fillet. J Food Process Preserv 42:e13336. https://doi.org/10.1111/jfpp.13336
38. Siripatrawan U, Vitchayakitti W (2016) Improving functional properties of chitosan films as active food packaging by incorporating with propolis. Food Hydrocoll 61:695–702. https://doi.org/10.1016/j.foodhyd.2016.06.001
39. Torlak E (2013) Antibacterial effectiveness of chitosan – propolis coated polypropylene films against foodborne pathogens. 60:52–55. https://doi.org/10.1016/j.ijbiomac.2013.05.013
40. Barrera E, Gil J, Restrepo A et al (2015) A coating of chitosan and propolis extract for the postharvest treatment of papaya (Carica papaya L cv Hawaiiana). Rev Fac Nac Agron Medellín 68:7667–7678. https://doi.org/10.15446/rfnam.v68n2.50982
41. Gniewosz M, Pobiega K, Kraśniewska K et al (2022) Characterization and antifungal activity of pullulan edible films enriched with propolis extract for active packaging. Foods 11:2319. https://doi.org/10.3390/foods11152319
42. Bertotto C, Bilck AP, Yamashita F et al (2022) Development of a biodegradable plastic film extruded with the addition of a Brazilian propolis by-product. LWT 157:113124. https://doi.org/10.1016/j.lwt.2022.113124
43. Marangoni Júnior L, de Gonçalves SA, da Silva RG et al (2022) Effect of green propolis extract on functional properties of active pectin-based films. Food Hydrocoll 131:107746. https://doi.org/10.1016/j.foodhyd.2022.107746
44. El Sheikha AF, Allam AY, ElObeid T et al (2022) Impact of a carboxymethyl cellulose coating incorporated with an ethanolic propolis extract on the quality criteria of chicken breast meat. Antioxidants 11:1191. https://doi.org/10.3390/antiox11061191
45. Ardjoum N, Chibani N, Shankar S et al (2023) Incorporation of Thymus vulgaris essential oil and ethanolic extract of propolis improved the antibacterial, barrier and mechanical properties of corn starch-based films. Int J Biol Macromol 224:578–583. https://doi.org/10.1016/j.ijbiomac.2022.10.146
46. Olewnik-Kruszkowska E, Gierszewska M, Wrona M et al (2022) Polylactide-based films with the addition of poly(ethylene glycol) and extract of propolis—physico-chemical and storage

properties. Foods 11:1488. https://doi.org/10.3390/foods11101488
47. Marangoni Júnior L, Jamróz E, de Gonçalves SA et al (2022) Preparation and characterization of sodium alginate films with propolis extract and nano-SiO2. Food Hydrocoll Heal 2:100094. https://doi.org/10.1016/j.fhfh.2022.100094
48. Barzaghi S, Cremonesi K, Cattaneo TMP (2017) Influence of the presence of bioactive compounds in smart-packaging materials on water absorption using NIR spectroscopy and aquaphotomics. NIR news 28:21–24. https://doi.org/10.1177/0960336017695731
49. Mustafa P et al (2020) PVA/starch/propolis/anthocyanins rosemary extract composite films as active and intelligent food packaging materials. J Food Saf 40:e12725. https://doi.org/10.1111/jfs.12725
50. Rollini M, Mascheroni E, Capretti G et al (2017) Propolis and chitosan as antimicrobial and polyphenols retainer for the development of paper based active packaging materials. Food Packag Shelf Life 14:75–82. https://doi.org/10.1016/j.fpsl.2017.08.011
51. Coma V (2010) Polysaccharide-based biomaterials with antimicrobial and antioxidant properties. Polímeros Ciência e Tecnol 20:. https://doi.org/10.4322/polimeros020ov002
52. Bankova V (2005) Recent trends and important developments in propolis research. Evidence-Based Complement Altern Med 2:29–32. https://doi.org/10.1093/ecam/neh059
53. Mascheroni E, Guillard V, Nalin F et al (2010) Diffusivity of propolis compounds in polylactic acid polymer for the development of anti-microbial packaging films. J Food Eng 98:294–301. https://doi.org/10.1016/j.jfoodeng.2009.12.028
54. Chang-Bravo L, López-Córdoba A, Martino M (2014) Biopolymeric matrices made of carrageenan and corn starch for the antioxidant extracts delivery of Cuban red propolis and yerba mate. React Funct Polym 85:11–19. https://doi.org/10.1016/j.reactfunctpolym.2014.09.025
55. Reyes LM, Landgraf M, Sobral PJA (2021) Gelatin-based films activated with red propolis ethanolic extract and essential oils. Food Packag Shelf Life 27:100607. https://doi.org/10.1016/j.fpsl.2020.100607
56. Safaei M, Roosta Azad R (2020) Preparation and characterization of poly-lactic acid based films containing propolis ethanolic extract to be used in dry meat sausage packaging. J Food Sci Technol 57:1242–1250. https://doi.org/10.1007/s13197-019-04156-z
57. Moreno MA, Vallejo AM, Ballester AR, et al (2020) Antifungal edible coatings containing Argentinian propolis extract and their application in raspberries. Food Hydrocoll 107:. https://doi.org/10.1016/j.foodhyd.2020.105973
58. Ebadi Z, Khodanazary A, Hosseini SM, Zanguee N (2019) The shelf life extension of refrigerated Nemipterus japonicus fillets by chitosan coating incorporated with propolis extract. Int J Biol Macromol 139:94–102. https://doi.org/10.1016/j.ijbiomac.2019.07.204
59. Mehdizadeh T, Mojaddar Langroodi A (2019) Chitosan coatings incorporated with propolis extract and Zataria multiflora Boiss oil for active packaging of chicken breast meat. Int J Biol Macromol 141:401–409. https://doi.org/10.1016/j.ijbiomac.2019.08.267
60. Silva AJ, Silva JR, De Souza NC, Souto PCS (2014) Membranes from latex with propolis for biomedical applications. Mater Lett 116:235–238. https://doi.org/10.1016/j.matlet.2013.11.045
61. Pires PG, Pires PD, Cardinal KM et al (2019) Effects of rice protein coatings combined or not with propolis on shelf life of eggs. Poult Sci 98:4196–4203. https://doi.org/10.3382/ps/pez155
62. Das DK, Dutta H, Mahanta CL (2013) Development of a rice starch-based coating with antioxidant and microbe-barrier properties and study of its effect on tomatoes stored at room temperature. LWT - Food Sci Technol 50:272–278. https://doi.org/10.1016/j.lwt.2012.05.018
63. Aygun A, Sert D, Copur G (2012) Effects of propolis on eggshell microbial activity, hatchability, and chick performance in Japanese quail (Coturnix coturnix japonica) eggs. Poult Sci 91:1018–1025. https://doi.org/10.3382/ps.2011-01944
64. Akpinar GC, Canogullari S, Baylan M et al (2015) The use of propolis extract for the storage of quail eggs. J Appl Poult Res 24:427–435. https://doi.org/10.3382/japr/pfv043
65. Zahid N, Ali A, Siddiqui Y, Maqbool M (2013) Efficacy of ethanolic extract of propolis in maintaining postharvest quality of dragon fruit during storage. Postharvest Biol Technol 79:69–72. https://doi.org/10.1016/j.postharvbio.2013.01.003
66. Cortés-Higareda M, de Lorena Ramos-García M, Correa-Pacheco ZN et al (2019) Nanostructured chitosan/propolis formulations: characterization and effect on the growth of Aspergillus flavus and production of aflatoxins. Heliyon 5:e01776. https://doi.org/10.1016/j.heliyon.2019.e01776
67. Kahramanoğlu İ (2020) Preserving postharvest storage quality of fresh loquat fruits by using different bio-materials. J Food Sci Technol 57:3004–3012. https://doi.org/10.1007/s13197-020-04333-5
68. Abou-Zeid RE, Diab MA, Mohamed SAA et al (2018) Surfactant-assisted poly(lactic acid)/cellulose nanocrystal bionanocomposite for potential application in paper coating. J Renew Mater 6:394–401. https://doi.org/10.7569/JRM.2017.634156
69. Pobiega K, Przybył JL, Żubernik J, Gniewosz M (2020) Prolonging the shelf life of cherry tomatoes by pullulan coating with ethanol extract of propolis during refrigerated storage. Food Bioprocess Technol 13:1447–1461. https://doi.org/10.1007/s11947-020-02487-w
70. Putra RE, Khairannisa S, Kinasih I (2017) Effect of application propolis as biocoating on the physical and chemical properties of tomatoes stored at room temperature. IOP Conf Ser Earth Environ Sci 58:012026. https://doi.org/10.1088/1755-1315/58/1/012026
71. Abo-Elyousr KAM, Seleim MEA, El-Sharkawy RM, Khalil Bagy HMM (2017) Effectiveness of Egyptian propolis on control of tomato bacterial wilt caused by Ralstonia solanacearum. J Plant Dis Prot 124:467–472. https://doi.org/10.1007/s41348-017-0120-x
72. Yang Y, Gong Y, Gao Y et al (2020) Study on the preservation effect of propolis on sweet cherry. IOP Conf Ser Earth Environ Sci 474:032029. https://doi.org/10.1088/1755-1315/474/3/032029
73. Khoshnevisan K, Maleki H, Samadian H et al (2019) Antibacterial and antioxidant assessment of cellulose acetate/polycaprolactone nanofibrous mats impregnated with propolis. Int J Biol Macromol 140:1260–1268. https://doi.org/10.1016/j.ijbiomac.2019.08.207
74. Putra RE, Reizandy F, Faizal A, Kinasih I (2018) Effication of local propolis as edible coating of tangerine cultivar Garut (Citrus reticulata Blanco). IOP Conf Ser Earth Environ Sci 187:012025. https://doi.org/10.1088/1755-1315/187/1/012025
75. Patel A, Hu Y, Tiwari JK, Velikov KP (2010) Synthesis and characterisation of zein–curcumin colloidal particles. Soft Matter 6:6192. https://doi.org/10.1039/c0sm00800a
76. Keskin M, Keskin Ş, Kolayli S (2019) Preparation of alcohol free propolis-alginate microcapsules, characterization and release property. Lwt 108:89–96. https://doi.org/10.1016/j.lwt.2019.03.036
77. Dalponte Dallabona I, de Lima GG, Cestaro BI et al (2020) Development of alginate beads with encapsulated jabuticaba peel and propolis extracts to achieve a new natural colorant antioxidant additive. Int J Biol Macromol 163:1421–1432. https://doi.org/10.1016/j.ijbiomac.2020.07.256

78. Donsì F, Ferrari G (2016) Essential oil nanoemulsions as antimicrobial agents in food. J Biotechnol 233:106–120. https://doi.org/10.1016/j.jbiotec.2016.07.005
79. El-Guendouz S, Aazza S, Lyoussi B et al (2018) Effect of poplar-type propolis on oxidative stability and rheological properties of O/W emulsions. Saudi Pharm J 26:1073–1082. https://doi.org/10.1016/j.jsps.2018.05.017
80. Fan Y, Ma L, Zhang W et al (2014) The design of propolis flavone microemulsion and its effect on enhancing the immunity and antioxidant activity in mice. Int J Biol Macromol 65:200–207. https://doi.org/10.1016/j.ijbiomac.2014.01.041
81. Elbaz NM, Khalil IA, Abd-Rabou AA, El-Sherbiny IM (2016) Chitosan-based nano-in-microparticle carriers for enhanced oral delivery and anticancer activity of propolis. Int J Biol Macromol 92:254–269. https://doi.org/10.1016/j.ijbiomac.2016.07.024
82. Chang X, Feng W, He L et al (2020) Fabrication and characterisation of whey protein isolate–propolis–alginate complex particles for stabilising α-tocopherol-contained emulsions. Int Dairy J 109:104756. https://doi.org/10.1016/j.idairyj.2020.104756
83. Salama A, El-Sakhawy M (2014) Preparation of polyelectrolyte/calcium phosphate hybrids for drug delivery application. Carbohydr Polym 113:500–506. https://doi.org/10.1016/j.carbpol.2014.07.022
84. Salama A (2018) Chitosan based hydrogel assisted spongelike calcium phosphate mineralization for in-vitro BSA release. Int J Biol Macromol 108:471–476. https://doi.org/10.1016/j.ijbiomac.2017.12.035
85. Salama A, El-Sakhawy M, Kamel S (2016) Carboxymethyl cellulose based hybrid material for sustained release of protein drugs. Int J Biol Macromol 93:1647–1652. https://doi.org/10.1016/j.ijbiomac.2016.04.029
86. El-sakhawy M, Salama A, Kamel S, Tohamy H-A (2018) Carboxymethyl cellulose esters as stabilizers for hydrophobic drugs in aqueous medium. Cellul Chem Technol 52:749–757
87. dos Reis AS, Diedrich C, de Moura C et al (2017) Physico-chemical characteristics of microencapsulated propolis co-product extract and its effect on storage stability of burger meat during storage at −15 °C. LWT - Food Sci Technol 76:306–313. https://doi.org/10.1016/j.lwt.2016.05.033
88. Duman M, Özpolat E (2015) Effects of water extract of propolis on fresh shibuta (Barbus grypus) fillets during chilled storage. Food Chem 189:80–85. https://doi.org/10.1016/j.foodchem.2014.08.091
89. Seibert JB, Bautista-Silva JP, Amparo TR et al (2019) Development of propolis nanoemulsion with antioxidant and antimicrobial activity for use as a potential natural preservative. Food Chem 287:61–67. https://doi.org/10.1016/j.foodchem.2019.02.078
90. Alsayed MFS, Hashem A, Al-Hazzani AA, Abd Allah EF (2020) Biological control of yeast contamination of industrial foods by propolis. Saudi J Biol Sci 27:935–946. https://doi.org/10.1016/j.sjbs.2020.01.023
91. Mattiuz B-H, Ducamp-Collin M-N, Mattiuz CFM et al (2015) Effect of propolis on postharvest control of anthracnose and quality parameters of 'Kent' mango. Sci Hortic (Amsterdam) 184:160–168. https://doi.org/10.1016/j.scienta.2014.12.035
92. Al-Qurashi AD, Awad MA (2018) Postharvest ethanolic extract of propolis treatment affects quality and biochemical changes of 'Hindi-Besennara' mangos during shelf life. Sci Hortic (Amsterdam) 233:520–525. https://doi.org/10.1016/j.scienta.2017.12.030
93. Fayaz G, Goli SAH, Kadivar M et al (2017) Potential application of pomegranate seed oil oleogels based on monoglycerides, beeswax and propolis wax as partial substitutes of palm oil in functional chocolate spread. LWT 86:523–529. https://doi.org/10.1016/j.lwt.2017.08.036
94. Vasilaki A, Hatzikamari M, Stagkos-Georgiadis A et al (2019) A natural approach in food preservation: propolis extract as sorbate alternative in non-carbonated beverage. Food Chem 298:125080. https://doi.org/10.1016/j.foodchem.2019.125080
95. Çoban MZ, Emir Çoban Ö, Fadiloğlu EE (2019) Microbiological and physicochemical quality of carp sausage enriched with propolis natural extract during chilled storage. J Aquat Food Prod Technol 28:960–966. https://doi.org/10.1080/10498850.2019.1665604
96. Salehi A, Rezaei A, Damavandi MS et al (2023) Almond gum-sodium caseinate complexes for loading propolis extract: characterization, antibacterial activity, release, and in-vitro cytotoxicity. Food Chem 405:134801. https://doi.org/10.1016/j.foodchem.2022.134801
97. Evangelista-Barreto NS, Falcão RSJ, Ferreira MA, et al (2022) Effect of chitosan coating incorporated with green propolis extract on pork meat during refrigerated storage. In: Open Science Research III. Editora Científica Digital, pp 256–269
98. Han S, Park H (2002) Accumulation of thiobarbituric acid-reactive substances in cured pork sausages treated with propolis extracts. J Sci Food Agric 82:1487–1489. https://doi.org/10.1002/jsfa.1216
99. Gumus D, Kizil M (2022) Comparison of the reducing effects of blueberry and propolis extracts on heterocyclic aromatic amines formation in pan fried beef. Meat Sci 186:108746. https://doi.org/10.1016/j.meatsci.2022.108746
100. Infante-Rodríguez F, Bautista-Martínez Y, Reyes-Cabrera B et al (2020) Use of propolis as a supplement in the diet of broiler chickens to increase shelf-life of breast muscle. CyTA - J Food 18:728–733. https://doi.org/10.1080/19476337.2020.1840445
101. de la Cruz-Cervantes JA, Benavides-González F, Sánchez-Martínez JG et al (2018) Propolis in aquaculture: a review of its potential. Rev Fish Sci Aquac 26:337–349. https://doi.org/10.1080/23308249.2018.1424798

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.