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FOOD INDUSTRY APPLICATIONS OF PROPOLIS: A REVIEW

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Abstract

Nowadays, the increasing consumer's demands for fresh and minimally processed foods without chemical additives attracted the research attention on some novel methods in food industry and use of natural compounds as alternative of chemical preservatives. As a unique natural product obtained from beekeeping, propolis possesses a wide range of biological activities and health benefits that can be used in food production and biopreservation. Propolis (bee glue) is a sticky resinous substance that is collected and processed by honey bees (*Apis mellifera* L.) from various plant sources such as flowers, leaf buds and tree exudates, and serving as a building and defensive material in their hives. This review discusses the trends in application of propolis as a safe, innovative and promising approach to quality improvement and natural preservation of different food products.

The broad antimicrobial spectrum of propolis against spoilage microorganisms and foodborne pathogens offers a great variety of applications in food industry for biopreservation of meat, fish and poultry products, eggs, milk and dairy products, perishable fruits, vegetables, fruit juices and other beverages. In addition to its antimicrobial potential, the strong antioxidant properties of propolis can contribute to increase the nutritional value of the products or to retard the lipid oxidation and protein degradation of processed foods. For this purpose, propolis can be added directly to the food matrix in the form of an extract, to be applied on the surface of the product as a bioactive film or edible coating, or to be included in the composition of food biopackaging materials, thus preventing the food spoilage and enhancing the storage life of the food products.

The present study on the applications of propolis in the food industry worldwide and its valuable properties reveals the potential of this natural product as a food additive, as a functional food ingredient, and as a prospective food biopreservative agent prolonging the shelf-life and improving the quality of food products.

***Key words**: Propolis, Bee products, Natural products, Food biopreservation, Functional foods.*

1. Introduction

Propolis is a unique natural product obtained from beekeeping and possessing valuable biological activities and health benefits. The word "propolis" used as a synonym of the bee glue is derived from the Greek ("pro polis" - "defence of the city") [1]. Propolis is a sticky substance produced by honey bees (*Apis mellifera* L.) that serves mainly as a building and defensive material. Bees use it to block holes and fill cracks, to smooth the internal hive walls, to repair and seal the honeycomb cells, and to embalm the carcasses of invaders who penetrated and died inside their hives, thus removing the unpleasant smell and bacterial flora accompanying their decomposition [2, 3]. In this regard, propolis plays an essential role in the social immunity of the honey bees: it can be considered an important part of the bees' immune system, protecting the bee colony from infectious and parasitic diseases due to its strong antimicrobial properties [4].

Propolis is a sticky resinous material with different color (green, red, yellow, and brown) that is collected and processed by honey bees from flowers, leaf buds and exudates of many plant species. In Europe, the primary sources of propolis are the resins of poplar (*Populus alba*, *P. tremula*, and *P. nigra*), birch (*Betula pendula*), pine (*Pinus* spp.), spruce (*Picea* spp.), fir (*Abies* spp.), alder (*Alnus glutinosa*), willow (*Salix alba*), acacia (*Acacia* sp.), horse chestnut (*Aesculus hippocastanum*),

oak (*Quercus* spp.), ash (*Fraxinus* spp.), etc. [5]. To produce propolis, the worker bees transport the raw plant material to their hive and mix it with beeswax and saliva, thereby obtaining a substance with highly adhesive consistency. The color, chemical composition, physicochemical properties and biological activity of propolis may vary greatly depending on the plant source, geographical and seasonal factors of the region from which it is obtained [4].

In recent decades, numerous studies have been conducted describing the complex chemical composition of propolis as a natural product. At present, more than 300 chemical compounds that belong to diverse chemical classes have been identified as constituents of propolis. Among the major components are polyphenols, represented mainly by flavonoids such as: tectochrysin, pinobanksin, pinocembrin, kaempferol, chrysin, galangin, and apigenin. The other biologically active compounds in propolis include aromatic acids (benzoic, coumaric, cinnamic, caffeic, ferulic, gallic, salicylic, vanillic), aromatic esters (cinnamic and caffeic acid ether esters), aliphatic acids (acetic, fumaric, angelic, crotonic, butyric, isobutyric, methylbutyric), aliphatic esters, volatile compounds (geraniol, nerol, farnesol, β-eudesmol), aromatic compounds (vanillin), hydrocarbons (eicosane, tricosane, pentacosane), steroids (cholinasterol, fucosterol, stigmasterol), enzymes (α- and β-amylase), waxy acids (arachid, palmitic, lauric, linoleic, oleic, stearic, myristic, cerotic), alcohols, aldehydes, ketones, amino acids, micro- and macronutrients (Ca, K, Mg, Na, Zn, Fe, Mn, Al, Ba, Cl), vitamins (B1, B2, B6, C, E), essential oils (monoterpenes and sesquiterpenes), sugars, pollen and other organic matter [6 - 9].

The rich chemical composition of propolis determines its high biological activity and a wide spectrum of pharmacological properties and potential health benefits. Propolis is a bioproduct that has been used in traditional and alternative medicine since antiquity, due to its immunomodulatory, antioxidant, anti-inflammatory, antibacterial, antiviral, antifungal, antiparasitic, anticarcinogenic, hepatoprotective, anti-ulcerogenic, anti-allergic, antidiabetic, astringent, anaesthetic, and other therapeutic effects. As a remedy, food supplement or functional food ingredient, propolis finds a wide application in medical practice to treat and prevent various diseases with great success [10, 11].

In recent years, the valuable biological properties of propolis attracted the research attention on its application in other scopes of life and fields of industry. The broad antimicrobial spectrum and great antioxidant potential of propolis made this natural product prospective for application in food biopreservation as an agent prolonging the shelf life of foods or improving the quality and safety of food products.

This review discusses the trends in application of propolis as a safe, innovative and promising approach to quality improvement and natural preservation of different food products.

2. Application of propolis in food industry

The increasing consumer's requirements for fresh and minimally processed foods without addition of chemical preservatives, have led to adoption of some innovative approaches in food processing and use of many natural compounds as biopreservatives. They derived from bacteria, fungi, plants or animals, with the aim of extending the shelf life of food products while guaranteeing their safety [12]. The broad antimicrobial spectrum, antioxidant properties and safety of propolis as a natural substance offer a great variety of applications in food industry that make it excellent mean for food biopreservation. Propolis can be added directly to the food matrix as an extract, to be applied on the surface of the product as a biofilm or edible coating, or to be included in the composition of food biopackaging materials.

2.1 Biopreservation of meat and fish products

Meat and meat products are major sources of high quality proteins and fats for the human nutrition. They are highly susceptible to microbial growth, and often act as vectors for various food spoilage microorganisms and foodborne pathogens. In addition to microbial spoilage, which creates a risk of food infections and intoxications, some meat products are susceptible to lipid oxidation. It can occur during the processing, distribution and storage of fermented meat products, altering their organoleptic properties and making them inappropriate for consumption. In this respect, propolis as a natural antimicrobial and antioxidant agent preventing these processes can find a wide application in the biopreservation of meat products.

The antioxidant and antimicrobial potential of propolis in biopreservation of meat products has been described in a number of studies. Kunrath *et al.*, [13], examined the antioxidant effects of propolis on Italian-type salami, found that propolis in concentrations of 0.01% and 0.05% inhibited oxidative action, and concluded that it can be added to this product as a natural antioxidant. The antioxidant properties of propolis in salami sausages were confirmed by Bernardi *et al.*, [14], who observed that microencapsulated and free propolis prevented the oxidation processes in the product during storage. Ali *et al.*, [15], investigated

the antimicrobial activity and antioxidant activity of 0.6% ethanolic extract of propolis in a freshly prepared oriental sausage. The authors stated that addition of propolis reduced the proteolytic, lipolytic, total mould and yeast counts, and significantly retarded the lipid oxidative changes in fresh sausage during the storage at 5 ^{0}C. Moreover, propolis treated sausages had longer shelf life (21 days) compared to the controls, which decomposed on the 12-th day of refrigerated storage.

Gutiérrez-Cortés and Suarez Mahecha [16], studied the effects of propolis in Chorizo sausage, and ascertained that application of ethanolic extract of propolis in concentration of 0.8 mg/mL improved some sensory properties and retarded protein degradation in treated sausages. *In vitro* antimicrobial testing demonstrated that propolis extract (0.8, 1.2 and 1.6 mg/mL) inhibited the growth of foodborne pathogens *Staphylococcus aureus*, *Escherichia coli*, *Salmonella* spp., and *Clostridium* sp. Casquete *et al.*, [17], examined the efficacy of ethanolic extract of propolis in Alheira (a fermented Portuguese meat sausage) on *Listeria innocua*, and found that the concentration of 0.28 mg/ml inhibited the growth of pathogen in food matrix during storage for 62 days at 4 ^{0}C. The authors stated that ethanolic extract of propolis reduced the *Listeria* population to below the detection limit after 8 days of storage. Other studies revealed the biopreservative effect of 2% ethanolic propolis extract in raw beef and pork patties. A significant decrease in lipid and protein oxidation as well as reduction of the mesophilic and the psychrotrophic bacterial counts by 1 log cfu/g and 3 log cfu/g, respectively during storage at 2 ^{0}C for 8 and 9 days was determined [18, 19].

The quality and shelf life of meat products can be improved also by surface application of propolis - singly or in the composition of edible coatings made of different biopolymers (cellulose, pectin, starch derivatives, etc.). Ozturk [20], evaluated the antifungal activity of propolis extract against natural microflora on the surface of Sucuk - a Turkish fermented dry-cured sausage. In Sucuk treated with propolis extract, the author observed reduction of yeast and mould counts with 2.05 log cfu/g compared to the control. The counts of lactic acid bacteria and aerobic mesophilic bacteria in Sucuk treated with propolis extract were similar to the initial levels by the end of ripening period. Surface treatment with propolis did not affect the overall appearance of Sucuk.

Fresh fish and seafood are extremely susceptible to spoilage in comparison with other food products due to the long-distance transportation from the catching areas to the consumers, and the additional time for their realization in the trade network. The recent approaches in preservation of fresh fish and fish products are directed towards the use of excessive amounts of salt or chemical preservatives that led to development of new methods for improving hygienic value and extending the shelf life such as application of bacteriocins, protective cultures of lactic acid bacteria [21, 22] or natural substances as propolis. Several studies on the promising biopreservative effects of propolis on fish products have been conducted. Payandan *et al.*, [23], evaluated the effects of three concentrations (3%, 5%, and 7%) of water and ethanolic extracts of Iranian propolis on the microbiological and sensory parameters of minced common carp (*Cyprinus carpio*) meat stored at 4 ^{0}C for 9 days. Obtained results showed that all concentrations of both types of extracts reduced the total plate, psychrotrophic and lactic acid bacteria, and *S. aureus* counts, while sensory characteristics were not improved significantly. The antimicrobial effectiveness of propolis in fish meat was investigated also by Hassanin and El-Daly [24]. The researchers stated that total bacterial count and psychrophilic bacterial count in Nile tilapia fillets (*Oreochromis niloticus*) treated with propolis extract (0.2, 0.4, and 0.6% aqueous solution) decreased during frozen storage at -18 ± 1 ^{0}C for 6 months. Mahecha *et al.*, [25], proved the preserving potential of ethanolic extracts of propolis (0.8% and 1.2%) in Cachama fish fillets (*Piaractus brachypomus*) during storage for 24 days at 4 ^{0}C with vacuum packaging.

2.2 Biopreservation of poultry products

Chicken meat is one of the most commonly consumed animal protein sources in many countries worldwide. Like the other types of meat, fresh chicken meat is a highly perishable product and it has a limited shelf life regardless of refrigerated storage. Deterioration in quality of refrigerated chicken meat at aerobic conditions is due to the growth and metabolic activities of psychrotrophic bacteria (*Pseudomonas* spp., *Enterobacteriaceae*, *Brochothrix thermosphacta*, and lactic acid bacteria), resulting in physicochemical and organoleptic changes. Besides the development of advanced methods for preservation of chicken meat such as vacuum and modified atmosphere packaging, they have demonstrated a limited contribution to its shelf life extension [26]. These limitations can be overcome by application of some biologically active and safe substances such as propolis. In this regard, to enhance the storage life of chicken fillet, Jafari *et al.*, [27], developed edible coatings based on chitosan (2%) containing ethanolic extract of propolis (1 and 2%). The obtained results demonstrated that coatings had a significant inhibitory effect on the growth of *S. aureus*, coliforms, aerobic mesophilic, psychotrophic, and lactic acid bacteria, and helped to maintain the sensory properties of the treated product during refrigerated storage at 4 ^{0}C for a period of 12 days.

Mehdizadeh and Langroodi [28], developed edible coatings based on ethanolic propolis extract and chitosan enriched with *Zataria multiflora* essential oil as an alternative method to preserve breast chicken meat under refrigerated conditions (4 ^{0}C). The results from microbiological analyses demonstrated a decrease in mesophilic bacteria, lactic acid bacteria, psychotropic bacteria and *Pseudomonas* spp. counts in the treated samples on the 16-th day of storage. The results from physicochemical analyses revealed a synergistic effect between the edible coating components in all treatments compared to the control. Thereby, the authors concluded that the application of edible coatings based on propolis, chitosan and *Zataria multiflora* essential oil is an effective approach for reducing microbial population and subsequent deterioration of fresh chicken meat.

Eggs are a rich source of essential nutrients, especially high quality protein necessary for the human diet. Under natural conditions, the egg's shell is exposed to microbial contamination, which can occur shortly after laying due to contact with faeces or dirty surfaces. Thus, the microorganisms can penetrate the egg through the shell pores making it perishable food and creating a risk for the consumer's health. Among the typical contaminants are *Salmonella*, *Pseudomonas*, coliforms, *Escherichia coli*, yeasts and fungi [29]. The egg's internal quality is additionally influenced by the aging process associated with water loss and gas diffusion through the pores [30]. Measures taken to extend the storage life are mainly directed to a reduction of microbial population on the egg's surface, and a limitation of moisture loss and gas permeability by covering the shell pores that can be applied along with conventional conservation methods (low temperatures). In this respect, the application of propolis as a safe product possessing high antimicrobial activity can be considered a prospective approach for egg disinfection and biopreservation [31, 32].

Several studies described the application of propolis as a mean for extending the shelf life of eggs. Propolis is a substance of hydrophobic nature, which included in the composition of various coatings, can enhance their water and gas barrier properties. Pires *et al.*, [30], developed rice protein coatings enriched with propolis extract, and found that coatings effectively reduced water loss and improved interior quality in treated hen's eggs during the storage at room temperature for up to 6 weeks. The bioprotective effect of propolis coatings on the internal quality parameters of hen's and quail's eggs stored at room temperature (25 ^{0}C) was confirmed by Copur *et al.*, [31], and Akpinar *et al.*, [32]. Other authors stated that spraying with 5, 10, and 15% propolis extract effectively reduced microbial activity on the surface of quail hatching eggs during storage at 13 ^{0}C and incubation without any detrimental effects on hatchability [33].

2.3 Biopreservation of milk and dairy products

Milk and dairy products are excellent medium for microbial growth, and similarly to meat and meat products, may play an important role in the transmission of various zoonotic pathogens causing salmonellosis, brucellosis, listeriosis, and tuberculosis. The pasteurization of raw milk before consumption or manufacture of dairy products is a technological process, which significantly decreases the number of microorganisms, but does not provide a sterile product [34]. Therefore, the survival of unwanted microflora is a substantial problem, which can be solved by application of some natural and safe preservatives in milk such as propolis. On the other hand, pasteurization treatment reduces the antioxidant activity of dairy beverages, therefore the addition of propolis can increase their antioxidant capacity, and prevent the lipid oxidation and associated aldehyde production [35].

The effects of propolis as a biopreservative in milk have been investigated by many authors. Thamnopoulos *et al.*, [36], examined the antimicrobial activity of ethanolic extract of propolis (with and without addition of glycerol) added to artificially contaminated with *Listeria monocytogenes* raw milk. The results showed that addition of propolis dissolved into glycerol resulted in a pronounced antimicrobial effect on *L. monocytogenes* in milk stored at 4 ^{0}C, with the higher concentration tested (4 mg of dry propolis per ml of milk) resulting in complete inhibition of the pathogen growth during storage for 30 days. The same combination (propolis with glycerol) was effective in significantly reducing the growth of *L. monocytogenes* in milk stored under improper refrigeration conditions (10 ^{0}C). A pronounced anti-listerial effect of ethanolic extract of propolis with and without glycerol (2 or 4 mg of dry propolis ethanolic extract per ml of chocolate milk) was observed also by Michailidis *et al.*, [37], into experimentally contaminated with *L. monocytogenes* pasteurized, non-fat chocolate milk stored at 4 ^{0}C and under improper refrigeration conditions (10 ^{0}C) for 20 days. In addition to the strong inhibitory effect on *L. monocytogenes*, authors noted a positive consumer acceptability of the chocolate milk with addition of propolis and glycerol. El-Deeb [38], found that supplementation of raw buffalo's milk with 2% water extract of propolis as a biopreservative was identified as the best method for improving the quality and microbiological parameters of milk. The buffalo's yoghurt with addition of 1% and 2% water extract of propolis showed the highest sensory evaluations, compared to the control sample.

Pedonese *et al.*, [39], studied the antimicrobial activity of an alcoholic extract of Italian propolis in sterile skim milk, pasteurized cow's milk, and cow's and goat's whey cheese (ricotta). The results demonstrated that 2% and 5% propolis extracts significantly reduced *L. monocytogenes*, *S. aureus*, *Bacillus cereus*, and *Pseudomonas fluorescens* counts in sterile skim milk. In pasteurized cow's milk the higher propolis concentration (5%) inhibited all pathogens, while 2% extract affected only *S. aureus* counts. In both types of ricotta cheese, 5% propolis extract decreased *L. monocytogenes* counts, whereas *S. aureus* and *B. cereus* counts remained unaffected. The authors concluded that propolis is prospective as biopreservative in ready-to-eat refrigerated dairy products.

Dairy products, especially hard cheese are highly susceptible to fungal growth, which may occur during the ripening, storage and distribution, resulting in deterioration of sensory properties of the product, potential toxicity for the consumers, and economic losses for the manufacturers. To avoid the fungal spoilage, many cheese producers use higher salt concentrations, weak acids, and antibiotics (natamycin). However, some antibiotics possess a negative impact on human health, which could be overcome by use of natural antimicrobials such as propolis. Aly and Elewa [40], applied water propolis extracts (250, 500, and 1000 ppm) on the surface of Egyptian Ras cheese and evaluated the antifungal effect on *Aspergillus versicolor* and biosynthesis of sterigmatocystin during the stage of ripening. The authors stated that the higher concentration of propolis (1,000 ppm) inhibited the fungal growth and toxin production during 3 months of ripening. Correa *et al.*, [41], examined the microflora on the surface of Gorgonzola-type cheese and evaluated the antifungal and antibacterial effects of ethanolic extract of propolis applied on the cheese. Besides the promising antimicrobial effect of propolis, the results from sensory analysis showed that 5% extract did not alter the organoleptic characteristics of cheese, while addition of 10% extract led to a slight decrease in the general acceptance from the consumers.

The antifungal effect of propolis on the surface of Bulgarian kashkaval cheese was determined by Tumbarski *et al.*, [42]. The authors stated that the application of three types of 1% ethanolic propolis extracts in the composition of carboxymethyl cellulose edible films led to significant inhibitory effect on the fungal growth and helped to prolong the shelf life of ripened Kashkaval cheese.

2.4 Biopreservation of fruits, vegetables and fruit juices

One of the most important problems associated with the storage life of fruits and vegetables is the fungal spoilage. The most common causes for post-harvest decay of fruits and vegetables are the fungal species *Botrytis cinerea*, *Penicillium* sp., *Rhizopus* sp., and *Mucor* sp. The fungal growth leads to deterioration of fruit quality, loss of commercially acceptable appearance, and creates a risk to the consumer's health. The proven harm of the chemical fungicides used for preservation of different fruits in the last few decades, led to the development of some new and safe methods for biopreservation using natural antimicrobial compounds.

Numerous studies consider propolis as a natural product for control of fungal pathogens and biopreservation of various fruits. Özdemir *et al.*, [43], determined the effects of three concentrations of ethanolic extract of propolis (1%, 5%, and 10%) on the storage life of Star Ruby grapefruit during storage at 8 ^{0}C for 6 months, and stated that 5% and 10% propolis effectively inhibited the fungal spoilage and retarded the decay changes in treated fruits. Yang *et al.*, [44], applied ethyl acetate extract of Chinese propolis to control *Penicillium digitatum* and *Penicillium italicum* on mandarins. The results indicated that propolis extract had a strong inhibitory effect on mycelial growth and spore germination of the tested fungal pathogens, and decreased decay changes and symptoms of blue and green mould in the treated fruit. Post-harvest decay and weight loss are important problems associated with the storage of other citrus fruits such as oranges, which can be solved by surface application (by dipping or spraying) of ethanolic propolis extracts [45]. Çandir *et al.*, [46], decreased the incidence of fungal decay, enhanced the commercial appearance and prolonged the post-harvest life in sweet cherries cultivar Aksehir Napolyon during refrigerated storage for 4 weeks after dipping the fruit in 1, 5, and 10% of ethanol-extracted propolis and 1, 5, and 10% of water extracted propolis. The application of ethanolic extract of propolis in concentration of 0.5% showed to have a strong inhibitory effect on the microbial growth of cucumbers [47].

Propolis extracts have been also used as alternative for sanitizing of leafy vegetables. To reduce the microflora in ready-to-eat and fresh whole head lettuces (*Lactuca sativa* L.) type Batavia, Feás *et al.*, [48], tested propolis solution on the lettuce surface for 15 and 30 min, and concluded that the propolis treatment was more effective in the reduction of aerobic mesophilic and psychrotrophic microorganisms in comparison with the conventional disinfectant sodium hypochlorite.

One of the most popular non-conventional approaches for biopreservation of perishable fruits is the application of edible coatings, which represent thin layers of biodegradable materials (polysaccharides, proteins, lipids or resins) that are applied to the fruit

surface. Their basic function is to protect treated fruits from mechanical damages, physical, chemical and microbiological activities, thus extending the storage life and reducing the economic losses of the fruit production. The inhibition of microbial spoilage and improvement of fruit storage life and nutritional value can be reached by incorporation of propolis in the composition of edible coatings. Pastor *et al.*, [49], investigated the effects of ethanolic extract of propolis included in hydroxypropyl-methylcellulose edible coatings on the quality and safety of muscatel table grapes. The obtained results demonstrated that edible coatings increased the microbial safety of fruit and exhibited a positive impact on postharvest characteristics during the storage period. Pobiega *et al.*, [50], studied the effects of pullulan-based edible coatings enriched with 5% and 10% propolis extract on reducing the microbial growth and physicochemical properties of fresh blueberry fruit during storage at 16 ^{0}C and 58 - 63% relative humidity for 21 days. The results demonstrated that the application of propolis-containing edible coatings reduced microbial count by 3 - 4.5 log cfu/g during the entire storage period. It was also found that edible coatings delayed ripening processes and decreased weight loss in treated blueberry fruit. During the storage, minor increase in titratable acidity values and no changes in the total soluble solids in coated blueberries in comparison with the control fruit were observed.

Fruit juices and soft beverages are products highly susceptible to microbial spoilage caused by bacteria, yeasts, and molds. Koc *et al.*, [51], examined the antifungal effect of ethanolic extract of Turkish propolis in four non-pasteurized fruit juices (apple, orange, white grape, and mandarin) against six different yeast strains isolated from the same spoiled juices (*Candida famata*, *Candida glabrata*, *Candida kefyr*, *Candida pelliculosa*, *Candida parapsilosis*, and *Pichia ohmeri*). The authors stated that the application of propolis in concentrations between 0.01 mg/mL to 0.375 mg/mL inhibited of all the tested yeasts at 25 ^{0}C, and possessed greater antifungal effect than the sodium benzoate used as a chemical preservative. The effectiveness of propolis has been determined also by Yang *et al.*, [52], who ascertained that addition of propolis emulsion (0.02 g/mL) showed significant antimicrobial effect and maintained the quality characteristics of orange juice up to 35 days, compared to the control, and the chemical preservatives sodium benzoate and potassium sorbate.

2.5 Application of propolis in food biopackaging

The general definition of biopackaging is related to the use of natural and synthetic biodegradable polymers, known as biopolymers, which serve to protect food and other products. Food biopackaging is an intelligent and eco-friendly approach, which main goals are to decrease the microbial spoilage, to increase the shelf life of food products by maintaining their quality, and to reduce the environmental pollution caused by the wide use of plastic packaging materials [53, 54].

The nature of biopackaging material is of paramount importance for its effectiveness in food preservation. According to the chemical structure, biopolymers used in biopackaging are produced from renewable sources and they can be classified into three major classes: polysaccharides, proteins, and polyesters. Based on the advances in biotechnology, biopolymers can be obtained by fermentation of microorganisms or by *in vitro* production by enzymatic processes [55]. The existing research data showed that polylactic acid (PLA) is among the most suitable structural matrices for the purposes of biopackaging production. Polylactic acid is a thermoplastic and thermostable biodegradable polymer, which is produced from non-toxic polysaccharide materials such as starch derivatives. Although they do not possess all required mechanical and barrier characteristics, PLA and similar biopolymers offer many advantages over the conventional packaging materials - they are non-toxic, safe for the consumer's health, recyclable and environment-friendly [56]. In addition, PLA exhibits excellent water vapor-permeability, which is important in the packaging of fresh food, and possesses good retention properties that allow the adhesion of different biologically active compounds, thus serving as a suitable carrier material [57, 58]. Another group of biopolymers used in the field of food biopackaging includes polyhydroxyalkanoates (PHAs) and bacterial cellulose that many bacterial species (*Alcaligenes*, *Azotobacter*, *Bacillus*, *Halobacterium*, *Rhizobium*) accumulate as a source of energy and as a carbon reserve. It was found that these biopolymers can find a wide range of food applications due to their good moisture vapor transmission rate and mechanical properties [58].

The incorporation of natural antimicrobial and antioxidant agents such as propolis in the composition of food biopackaging materials is a promising alternative strategy to avoid the food spoilage and to improve the shelf life of different food products. The main function of food biopackaging materials is to release the incorporated bioactive compound slowly into the food matrix, thus to prevent microbial growth. According to their volatility, bioactive compounds in food packaging systems could be classified in two groups - volatile compounds that inhibit microbial growth by direct or indirect contact between the packaging material and the food, and non-volatile compounds that require direct contact between the food and the packaging to be efficient

[57]. Rollini *et al.*, [59], developed a new approach in food biopreservation by incorporation of chitosan and propolis in cellulose-based packaging materials. The results showed that paper sheets produced by wood pulp with addition of carboxymethyl cellulose, microfibrillated cellulose, chitosan and propolis glycolic extract, demonstrated promising polyphenols retention properties, wet strength and wet resistance. The antimicrobial activity of obtained paper based biopackagings was tested on artificially inoculated with *L. innocua* sliced raw veal meat, where the decrease of the pathogen in inoculated samples was detected at the 48th hour. Some other authors examined the combination of starch, chitosan and propolis in active packaging production. In this regard, Suriyatem *et al.*, [60], developed biofilms from rice starch and carboxymethyl chitosan, incorporated with propolis extract, and determined that biofilms containing 5% and 10% propolis extract had antimicrobial activity against *S. aureus* and *B. cereus*. Moreover, the active film enriched with 10% propolis extract exhibited enhanced flexibility and thermal stability, without a change in oxygen permeability. Mustafa *et al.*, [53], developed active food packaging films based on the biopolymers polyvinyl alcohol and starch, incorporated with propolis ethanolic extract. The obtained biofilms demonstrated significant antimicrobial activity against the foodborne pathogens *E. coli* and methicillin-resistant *S. aureus*, and protected the samples of pasteurized milk used in spoilage test. Some recent studies revealed that reinforcement of pullulan/chitosan-based edible film with mushroom-mediated zinc oxide nanoparticles (ZnONPs) and propolis extract improved the mechanical strength, and increased the water vapor barrier property and hydrophobicity of the biofilm. The developed biopackaging material proved to be effective in reducing the peroxide value and the total aerobic bacterial count in the treated pork meat [61].

In conclusion, food biopackaging from renewable sources is one of the most promising solutions against the environmental pollution and toxicity of the non-degradable materials such as polyethylene, polypropylene, and polystyrene, which create health hazards due to migration of toxic compounds into the food matrix. The addition of some natural antimicrobials and antioxidants such as propolis in the composition of biopackaging materials represents a prospective approach for preventing the microbial spoilage, for improving the quality and safety, and for prolonging the shelf life of food products.

3. Conclusions

- Propolis is one of the most unique bee products possessing a broad range of biological activities and health benefits, and widely used in different forms all over the world.
- The rich chemical composition and valuable properties of propolis offer a great potential for application in the food industry as a natural and safe preservative with high antimicrobial and antioxidant activities, and as a means of increasing nutritional value of foods.
- By inhibition of spoilage microorganisms and foodborne pathogens, and reduction of the lipid oxidation processes, propolis can prevent undesirable physical, chemical, microbiological and organoleptic changes in the food, thus to protect the quality and enhance the shelf life of the food products of plant and animal origin.

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