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Review Article

Biochemical Composition of Propolis and Its Efficacy in Maintaining Postharvest Storability of Fresh Fruits and Vegetables

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Propolis, also called "bee-glue," is a natural resinous substance produced by honeybees from plant exudates, beeswax, and bee secretions in order to defend the hives. It has numerous phenolic compounds with more than 250 identified chemical compounds in its composition, which are also known to significantly vary according to the plant sources and season. Moreover, it has a long history in the traditional and scientific medicine as having antibacterial, anticancer, anti-inflammatory, anti-infective, and wound healing effects since 300 BC. In addition to its nutritional and health-promoting effects, it has been reported to improve the postharvest storability of fresh fruits, vegetables, and processed food products. Herein, the biochemical composition and the efficacy of propolis in maintaining the postharvest storability of fresh food products were discussed to provide comprehensive guide to farmers and food processing and storage sectors and to scientists. This review paper also highlights the important points to which special attention should be given in further studies in order to be able to use propolis to develop biopreservatives industrially and for quality preservation during storage.

1. Introduction

Numerous scientists warn humanity about the fact that the most important global issues in near future will be food safety and security. It has been estimated that by 2050, the human population worldwide will exceed 9 billion while the available natural resources required for food production (i.e., soil and water) have a diminishing trend [1–4]. This will unfortunately make it impossible, or let us be a little more positive, very difficult to feed the humanity and to ensure the health of the planet and humanity, if suitable measures are not taken. It is not that difficult to come up with this thought, when the reports of the FAO [5] says that around 821.6 million people (~10.8% of the total population) have suffered from chronic hunger in 2018. To overcome this challenge in large scale, one widely appraised solution is to address these four pillars: food availability, access, utilization, and stability [6, 7]. As seen from the appraised solution, food utilization (handling and storage) is as important as its production. It was estimated that the postharvest loss during utilization throughout the world is around 30–50%, depending on the product and place; and it goes to waste [3, 8]. This alone is an important part of the four pillars of the solution. Thus, efficient and safe measures are of utmost importance to reduce postharvest loss and wastes during harvesting, processing, storage, distribution, and retail and in households.

Agrochemicals have a vital role in production, protection, and preservation of the fresh products and are still the primary preferences of growers for crop production and prevention of food losses [9]. However, it has been reported that the misuse of chemical fungicides reduces the efficacy of the fungicides by causing resistant fungi strains [10]. Besides the reducing efficacy of agrochemicals in time, excessive use of agrochemicals has been the subject of public discussions among scientists, consumers, and the media, and this reduces their acceptability by the consumers [11, 12]. Thus, this is a double-edged challenge for the growers as they have to reduce/eliminate postharvest losses to ensure food security, while at the same time they have to ensure food safety by eliminating any negative effects of agrochemicals. At this point, development of alternative human/ecofriendly measures to agrochemicals has been an important subject for the scientific world [13]. In this context, numerous studies have been conducted to develop human/ecofriendly alternatives and suggested many biomaterials or measures for the prevention of the postharvest losses: hot water dipping (HWD) [14], hot air treatment (HAT) [15], salts [16], light irradiation [17], modified atmosphere packaging (MAP) [18], edible coatings [19, 20], plant extracts [21–24], essential oils [25, 26], chitosan [27, 28], and propolis [29, 30]. Among these, propolis has an important role in prevention of food loss and waste, thus helping to ensure food safety and security. Herein, the biochemical composition and efficacy of propolis in maintaining the postharvest storability of food products were discussed to provide a comprehensive guide to farmers and food processing and storage sectors and to scientists.

2. Biochemical Composition (Phenolic Acids, Flavonoids, Vitamins, and Others)

Propolis is a natural hive defensive resinous substance produced by honeybees from plant exudates, beeswax, and bee secretions. Propolis which is also called "bee-glue" is collected by honeybees from a variety of plant resinous secretions, i.e., gums, resins, leaf buds, and mucilage [31, 32], from numerous plant species, such as conifers, pine, palm, poplar, and birch [33], and is used to build structures in their hives and to fill the holes in to protect their hives from microbes and other external threats [34]. It has a long history in medicine as a wound healing agent and having antibacterial, anticancer, anti-inflammatory, and anti-infective effects since 300 BC [35–39]. It is reported that its composition significantly varies according to the plant sources and season and it is composed of about 50% resin, 30% wax, 10% essential oils, 5% pollen, and 5% other substances [34]. According to the review of Anjum et al. [40], the numbers of identified chemical components of propolis have exceeded 250. The general groups of the chemical components are alcohol and its derivatives, aliphatic acids, aliphatic esters, aliphatic hydrocarbons, amino acids, benzaldehyde derivatives, benzoic acid and its derivatives, cinnamic acid and its derivatives, dihydrochalcones, enzymes, esters, fatty acids (C7–C18 acids), flavonoids, heteroaromatic compounds, ketones, minerals, nicotinic acid, pantothenic acid, chalcones, phenols, sesquiterpene, sesquiterpene, steroid hydrocarbons, sterols, sugar, terpene, triterpene hydrocarbons, vitamins, and waxy acids. The chemical composition of propolis was noted to have high variation apparently related to plant sources [41].

In one of the most recent studies, Chaa et al. [42] tested the chemical composition of ethyl acetate extract of propolis (EAP: 10 g of crude propolis crushed and extracted three times with ethanol 95%) collected from Tigzirt, Algeria. Researchers noted that the chemical composition of the propolis samples which were made by a certain breed of bees (*Apis mellifera intermissa*) have 17 different chemical compounds. They noted that the main phenolic compound was caffeic acid ($0.85\,mg{\cdot}g^{-1}$ EAP) and the main flavonol compound was pinocembrin ($0.82\,mg{\cdot}g^{-1}$ EAP). A study on propolis extracts collected from Polland showed that the chemical composition highly depends on the season [43]. In this study, samples were reported to be collected in three different seasons: spring (4^{th} to 6^{th} month), summer (6^{th} to 9^{th} month), and fall (9^{th} to 11^{th} month). The extraction method of the propolis in that study differed from the studies in [42], where 70% ethanol was used in $1:10$ (w/v) and the solution was called ethanolic extracts of propolis (EEP). The highest sums of the determined flavonoids and phenolic acids were both noted in the samples harvested in spring as 125.14 and $19.34\,mg{\cdot}g^{-1}$, respectively. The lowest sum of the phenolic acids was noted in the summer samples ($16.18\,mg{\cdot}g^{-1}$), where the lowest sum of total flavonoids was in the samples of fall season ($110.09\,mg{\cdot}g^{-1}$) (Table 1).

The main flavonol compound was found to be pinocembrin, but the concentrations were very high in EEP extracts as compared with EAP. Most of the flavonoids in these studies were common, but some were not, such as acacetin, myricetin, and galangin. Similar results were noted by Valencia et al. [45] for Sonoran propolis. In the mentioned study, it was noted that the both phenolic acids and flavonoids decrease in spring, while the total phenolics are highest in fall and total flavonoids are highest in summer [45]. These biochemical compounds are known to have high antioxidant and antimicrobial activities [44]. The propolis samples have also been suggested to be divided into two main groups, orange (O) and blue (B), according to the colours of the phenolic profiles in HPTLC analysis [46, 47], but a third group was also noted by some reports as green (G) or third band [44, 48]. The bands with strong orange colour are distinctive with flavonoids (i.e., quercetin) and the blue bands generally include caffeic acid. A summary was given in Table 1 for the Turkish propolis subtypes [44].

3. Antimicrobial and Fungicidal Effects

Microbial decay caused by fungi and/or bacteria is an important problem for the postharvest storability of the food products, including fresh fruits and vegetables and processed foods. It has been reported to reach very high levels in different kinds of fruits such as *Penicillium italicum* Wehmer (blue mold) and was noted to cause up to 80% loss in citrus fruits [49]. Due to the scientifically confirmed health benefits of the propolis, most of the previous studies about the fungicidal effects of propolis have been conducted on the human damaging microbes, such as *Candida albicans* [44]. The strong antimicrobial activity of the propolis extracts was

Table 1: Phenolic compositions of different propolis derivates from different plant sources, seasons, and types.

Phenolics	$mg{\cdot}g^{-1}$ of EAP [42]	$mg{\cdot}g^{-1}$ of EEP [43]			$mg{\cdot}mL^{-1}$ of EEP [44]		
		Spring	Summer	Fall	Orange-type	Blue-type	Green-type
Phenolic acids							
Caffeic acid	0.85	3.90	3.26	3.68	34.78	24.82	3.96
Ellagic acid	0.60	No	No	No	No	No	No
p-Coumaric acid	0.41	10.00	9.17	10.04	4.91	3.13	0.19
Cinnamic acid	0.34	No	No	No	5.19	3.00	5.28
Gallic acid	0.29	No	No	No	No	No	No
Chlorogenic acid	0.20	No	No	No	No	No	No
Rosmarinic acid	0.18	No	No	No	No	No	No
Ferulic acid	0.05	3.80	2.61	3.63	19.42	9.63	1.00
Vanillic acid	No	0.46	0.31	nd	0.39	0.30	0.27
Syringic acid	No	1.18	0.83	1.01	No	No	No
Protocatechuic acid	No	No	No	No	1.69	0.71	0.45
Flavonoids							
Pinocembrin*	0.82	51.55	41.55	50.34	2.81	2.16	0.94
Catechin	0.78	No	No	No	No	No	No
Quercetin	0.76	4.29	4.03	3.83	4.33	2.85	1.11
Chrysin	0.55	19.51	14.40	15.32	2.22	1.85	1.54
Kaempferol	0.31	10.43	11.51	5.01	1.76	0.92	0.44
Acacetin	0.17	No	No	No	No	No	No
Rutin	0.01	0.72	0.56	0.49	0.36	0.47	0.16
Apigenin	0.01	6.03	7.94	10.01	No	No	No
Myricetin	No	0.63	0.39	0.83	No	No	No
Galangin	No	26.89	32.53	20.14	2.70	1.67	0.96
Naringenin	No	0.88	0.83	0.83	No	No	No
Pinobanksin	No	4.21	3.83	3.29	No	No	No
Luteolin	No	No	No	No	1.57	0.24	0.31
Apigenin	No	No	No	No	1.56	1.05	0.54

No represents "no available information"; nd means "not detected" from Turkey. *Flavanone: a type of flavonoid.

attributed to the high concentrations of cinnamic acid, ferulic acid, and caffeic acid [50, 51]. Furthermore, there are numerous studies about its efficacy on food damaging pathogens. In general, two different mechanisms were suggested in the literature for the antimicrobial efficacy of the propolis: (1) direct influence on the pathogens by prevention of some biochemical reactions and (2) improving resistance of products to the pathogens by enhancing some other biochemical reactions [52–55].

Ethanolic extracts of propolis (first dissolved in 70% ethanol in a ratio of 1 : 10 (*w*/*v*) and then diluted with pure water in a ratio of 1 : 10 (*w*/*v*) to obtain 1.0% dose) was reported to significantly reduce gray mold (*Botrytis cinera*) development on pomegranate fruits [30]. The studies on pomegranate fruits also suggested that the EEP has a significant influence on the prevention of the antioxidant activity and anthocyanin contents, which might be attributed to the fungicidal activity of the propolis. By following the same extraction method, 0.5% dose of EEP then showed to have a potential to reduce the microbial growth on the cucumber fruits [56]. Different doses (30, 50, 70, and 100%) of ethanolic extract of propolis (EEP) (ratio of propolis to 80% ethanol was 1 : 10 *w*/*v*) was noted to significantly reduce the growth of 19 different yeast strains isolated from industrial foods in *in vitro* conditions. It was noted that the antimicrobial ability of EEP against the yeast strains differ significantly where the lowest effect was suggested for *Candida famata* and the highest efficacy for *Candida laurentii*. The efficacy of the propolis was attributed to its characteristics in inhibition of cell division and causing cell rupture [57]. Similar results were previously suggested by Takaisi-Kikuni and Schilcher [58] who reported that the propolis have a possible mechanism for inhibiting cell division and causing surface alteration of the cells. The inhibitory effects of propolis, in a different study, was also attributed to the possible mechanism for inhibiting protein synthesis and some functions of the cell membrane, where the flavonoid quercetin was suggested to be responsible for this mechanism [50]. The study by Alsayed et al. [57] also showed that the propolis treatment reduces the activity of oxidative enzymes, together with catalase activity, superoxide dismutase activity, and ascorbate activity in yeast. Oxidative enzymes are important for the catalyzation of the oxidation reaction and reduction in these activities and might be a cause of the discouraging the growth of the yeast. Similarly, the application of propolis was noted to reduce reactive oxygen species (ROS) generation and lipid peroxidation [57]. In an *in vitro* experiment with mango fruits (var "Kent"), different doses of propolis (0, 0.25, 0.5, 1.0, 1.5, and 2.0% *w*/*v*) were tested against anthracnose development and reported that the 1.5% dose is highly effective in spore suspension [53]. Application of propolis was also found to significantly induce inhibition of the mycelial growth of *Penicillium digitatum* [59, 60]. In each of these studies, the capability of propolis to inhibit the pathogenic development was attributed to its high contents of phenolic compounds. The application of propolis to the plants or fruits was also noted to enhance Cu/Zn-SOD and protect plant cells, thus improving the resistance of the crops to the pathogens. The antimicrobial efficacy of propolis was confirmed in a number of studies for mango fruits [53, 55], papaya fruits [52], orange [54, 61], and pomegranate juice [62]. Antifungal activity of ethanolic extract of propolis was also tested on raspberry fruits against *P. digitatum*, *P. expansum*, *P. italicum*, *A. alternata*, *A. carbonarius*, and *B. cinerea*. Gelatin-based edible coatings by propolis were tested, and the active films showed a high antifungal activity against the tested fungus [63]. It was also noted that the incorporation of propolis with chitosan provides higher antimicrobial activity [64, 65]. In one of these studies, Correa-Pacheco et al. [64] noted that the propolis-containing formulations (10%, 20%, and 30%) had a strong inhibitory effect on *Listeria monocytogenes* and 10% formulation had a similar effect on *Escherichia coli* and provided better preservation of strawberries. In a different study, *in vivo* and *in vitro* trials were conducted to test the efficacy of propolis extracts on the *Stemphylium vesicarium* (Wallr.) E. G., which is the cause of brown spot disease in pear fruits. Researchers noted that the propolis extracts provides 90% reduction in the mycelial growth in *in vitro* studies and up to 57% in *in vitro* studies [66].

Previous studies also recommended that ethanol, methanol, alcohol, acetone, or some other solvents may have a significant influence on some fungus and/or bacteria [67–69]. However, nearly all of the studies on propolis also tested the efficacy of the solvent and those studies reported that although the solvent might improve the efficacy of propolis, the antimicrobial and fungicidal efficacies are mainly due to the propolis itself.

4. Effects on Food Quality Characteristics

Food quality characteristics are generally classified in three groups, which are (1) external quality characteristics (visual quality, size, colour, etc.) (2) internal quality characteristics (internal colour, juice content, texture, taste, number of seeds, etc.), and (3) hidden quality characteristics (nutritional status and safety) [3]. The aim of the postharvest handling is not only to maintain the external quality characteristics, but also the internal quality attributes, without damaging the hidden quality characteristics of the foods. In this context, propolis as a natural product has a significant role in maintaining the postharvest storability of food products. Results of existing literature was discussed in the following sections, separately for each quality parameter, and a summary is presented in Table 2.

4.1. Effects on Weight Loss. Weight loss, together with the microbial decay, could be accepted as the most important problems related with postharvest storage of the foods. The main reasons of the weight loss are the ongoing transpiration (loss of water from the living tissues) and the respiration (loss of carbohydrates) of the foods after harvest/processing [3, 78]. Thus, reducing the weight loss is highly related with the reduction of respiration and transpiration. The hydrophobic composites of propolis extracts, with its high phenolic concentration, are capable of forming a biodegradable barrier on fruit surface which prevents the movement of water and gaseous through the food surface [73, 74]. In confirmation of this knowledge, propolis treatment has been reported to reduce weight loss of various foods during storage such as pomegranate [30], mango [55], papaya [52, 70, 71], banana [72], dragon fruit [73], orange [54, 61, 74], and cucumber [56]. Such reduction in the weight loss might be explained by the characteristics of propolis about the prevention of transpiration and respiration. In one of these studies, the ethanolic extracts of propolis, at a rate of 1.0%, were found to protect pomegranate fruit weight during storage at $6.5 \pm 1^{\circ}C$ and 90–95% relative humidity. It was noted that the weight losses of fruits treated with propolis and those untreated were 11.3% and 19.8%, respectively, 150 days after storage. In the same study, it was also noted that the incorporation of propolis with modified atmosphere packaging provides better preservation of the fruit weight [30]. Propolis alone (EEP at 0.5% dipping dose) was also found to keep the weight loss of cucumber fruits at 15.40% in 24 days of storage, where the weight loss was 26.72% at the untreated control fruits; the combination of propolis with MAP was suggested to provide better control of the weight loss which was reported as 3.58% [56]. The application of 2% and 3% alcoholic extract of propolis was then recommended to provide higher efficiency in prevention of the weight loss at "Washington Navel" oranges. The efficacy of 3% propolis in the mentioned study was significantly similar to the commercial wax which has high attention in the citrus industry [61]. Studies with papaya cv. "Golden" (*Carica papaya* L.) showed that the 2.5% propolis coating improves the storability of fruits by reducing the weight loss and improving some other quality characteristics [70]. However, it is also important to note that ethanol, which is the main solvent used for propolis, alone was shown to provide a blocking at stomata and results with reduction in transpiration and respiration and in conclusion in weight loss [52]. In addition to this knowledge, there is one another study suggesting that ethanol application alone does not provide any positive influence on the retention of the fruit quality due to its volatile nature [79]. In a similar study, both the aqueous and alcoholic extracts of propolis were noted to have no significant influence on the postharvest quality of "Eva" organic apple and do not prolong its storability at $5 \pm 1^{\circ}C$ [77].

4.2. Effects on Chilling Injury. Storage temperature is the most important environmental factor which significantly reduces respiration, transpiration, and pathogens development, which are the main causes of weight and quality losses, but lowering the temperature below critical levels (changing depending upon the crops) causes damages on the food products, namely, chilling injury. The critical range for the temperature changes among the varieties, but it is mainly

Table 2: Summary of the existing literature on the postharvest efficacy of propolis on food storability.

Crops	Treatment (doses)	WL	CI	SSC	TA	VC	TPC	AA	F	S	DI	Reference
Pomegranate	Dipping in 1.0% EEP (70% ethanol)	+	+	+	+	+	n/a	nu	n/a	+	+	[30]
Mango	Dipping in 2.5%, 3.5%, and 4.5% EEP (70% ethanol)	+	n/a	+	+	n/a	+	n/a	+	n/a	+	[53]
Papaya	Coating with 2.5% aqueous extract	+	n/a	nu	nu	n/a	n/a	n/a	+	+	n/a	[70]
Papaya	Dipping in 1.5% and 2.0% EEP (70% ethanol)	+	n/a	+	+	n/a	n/a	n/a	+	n/a	+	[52]
Papaya	Dipping in 2.5% and 5.0% EEP (70% ethanol)	+	n/a	+	n/a	n/a	n/a	n/a	+	+	n/a	[71]
Banana	Coating with 2.5% EEP (70% ethanol)	+	n/a	+	+	n/a	n/a	n/a	+	+	n/a	[72]
Dragon fruit	Dipping in 0.75% and 1.0% EEP (70% ethanol)	+	n/a	+	+	n/a	+	+	+	n/a	n/a	[73]
Orange	Coating with 2.5% and 5.0% EEP (70% ethanol)	+	n/a	+	+	n/a	n/a	n/a	+	n/a	n/a	[74]
Orange	Dipping in 2.0% EEP (70% ethanol)	+	n/a	+	+	+	n/a	n/a	n/a	n/a	+	[54]
Orange	Coating with 2.0% and 3.0% alcoholic extract	+	n/a	nu	+	+	n/a	n/a	n/a	+	+	[61]
Cucumber	Dipping in 0.5% EEP (70% ethanol)	+	+	+	n/a	n/a	n/a	n/a	nu	+	+	[56]
Tangerine	Dipping in 5%, 10%, and 15% EEP (70% ethanol)	nu	n/a	+	+	+	n/a	n/a	n/a	+	n/a	[75]
Sweet cherry	Dipping in 0.5%, 1.0%, 1.5%, and 2.0%	+	n/a	+	+	+	n/a	n/a	+	n/a	n/a	[76]
Raspberry	Edible film coating with 8% EEP (80% ethanol)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	+	+	[63]
Strawberry	Edible film with 10%, 20%, and 30% EEP (70% ethanol)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	+	[64]
Pear	Spraying with 30.0 mg/mL or 6.0 mg/mL EEP (70% ethanol)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	+	[66]
Apple	Dipping in 1.5% and 2.5% EEP (70% ethyl alcohol and aqueous extract)	nu	n/a	nu	nu	n/a	n/a	n/a	n/a	nu	n/a	[77]
Pomegranate juice	1 drop of EEP (1 : 10 in 70% ethanol) per 250 ml of juice	n/a	n/a	+	+	+	n/a	+	n/a	n/a	+	[62]

WL: weight loss; CI: chilling injury; SSC: soluble solids concentration; TA: titratable acidity; VC: vitamin C (ascorbic acid); TPC: total phenolic content; AA: antioxidant activity; F: firmness (textural quality); S: sensory or visual acceptability; DI: decay incidence; n/a: no data available; +: positive influence; −: negative influence; nu: neuter effect.

below 5°C–13°C [3]. Low temperatures cause various physiological and biochemical changes which lead to the development of different symptoms, for example, surface pitting, flavor loss, discoloration, wilting, and internal breakdown. Dipping of pomegranate and cucumber fruits into 1.0% and 0.5%, respectively, of ethanolic extracts of propolis, was noted to reduce the severity of chilling injury on the fruits [30, 56]. No recommendations were given on the mechanism behind this preservation, but the results may suggest that the increase in the phenolic contents and ascorbic acid in pomegranate fruits might be the main cause of this preservation.

4.3. Effects on Soluble Solids Content and Titratable Acidity. Soluble solids concentration (SSC) and titratable acidity (TA) are the main determinants of the food taste. Thus, the prevention of the losses of SSC and TA is highly important for keeping the acceptability of the foods by the consumers. The effect of propolis on the fruits' SSC and TA was noted to vary among the fruit species such that no significant influence was reported for the SSC and TA of mango fruits [53], papaya fruits [70], and orange fruits [61], while a positive influence on the prevention of both SSC and TA was noted for pomegranate fruits [30], mango fruits [55], papaya fruits [52], banana fruits [72], dragon fruits [73], orange fruits [54, 74], and pomegranate juice [62]. The positive influence of propolis extracts on the SSC levels could be explained by the similar mechanism of weight loss prevention, which is the formation of a semipermeable and biodegradable barrier around the food which suppresses some biochemical reactions, including the most important one: respiration [3, 73, 80]. A similar mechanism exists for the TA, and in general it is known that the increase in respiration rate causes a decrease in TA; thus, reduction of the respiration provides a reservation of the TA in fruits [81].

4.4. Effects on Vitamin C (Ascorbic Acid) Contents. Vitamin C (VC, ascorbic acid) is an important water soluble compound and has high antioxidant capacity, helping human cells in fighting with microbial infections, protecting cells from damage, and reducing oxidative stress in human body. Although there are numerous studies about the influence of propolis on the storability of food products, most of these studies had not reported any positive or negative influence on the VC content. In a limited number of studies, it was noted that the postharvest application of propolis has a positive influence on the prevention of VC contents of pomegranate fruits [30], orange fruits [54, 61], tangerine fruits [75], and pomegranate juice [62]. Vitamin C is known to have a decreasing trend during the storage period of the fruits, and propolis was found to have a positive influence on the prevention of the decrease in VC at "Washington Navel" orange fruits. Further studies are highly necessary about the efficacy of propolis on the VC contents of foods during storage.

4.5. Effects on Phenolic Contents. Phenolic compounds (PCs) are important phytochemicals found in most plant tissues, which are synthesized through secondary metabolisms and are called secondary plant metabolites. Even though they are not nutrients, they possess numerous bioactive properties and are known to have high antioxidant activity and provide health-protective effects. They also have significant roles in the plants' defensive system against pests, diseases, or abnormal environmental conditions [82]. Therefore, prevention and/or inducement of the biosynthesis of the phenolic compounds in food products might be a cause of the preservation of the postharvest quality of foods. Higher rate of respiration is known to result in the degradation of certain phenolic compounds. Thus, the prevention of respiration might be a reason for the prevention of the degradation and reduction of phenolic compounds. The number of studies about changes in phenolic compounds due to the application of propolis is limited but the results are valuable. It was noted that propolis treatment prevents the degradation of the phenolic compounds at mango [53, 55] and dragon fruits [73].

4.6. Effects on Antioxidant Activity. Antioxidant activity is an important example of functional benefits of plants which directly scavenge free radicals and prevent/reduce the oxidation of lipids, proteins, DNA, or other molecules and/or indirectly prevent the formation of free radicals [83]. Thus, the change in the antioxidant activity of the foods during storage is an important parameter and always needs to be at higher levels. Herein, the effects of propolis on the antioxidant activity of different food products were summarized. For example, no significant influence was noted for the antioxidant activity of pomegranate fruits [30] and mango fruits [53]. Positive influence for the propolis treatment on the prevention of the antioxidant activity was also suggested for dragon fruit [73] and pomegranate juice [62].

4.7. Effects on Textural Quality. Textural quality of foods, which is mainly described by firmness, is also important for the consumers' acceptability of the food products. Propolis treatment, as suggested previously, provide a semipermeable and biodegradable film on fruit surface and regulates the movement of gases and water in/out from the food tissues; thus, it maintains cell turgidity and firmness of fruit [52, 72, 73]. In confirmation of this knowledge, numerous studies reported success about the preventive characteristics of propolis for the fruit firmness, such as in mango fruits [55], papaya fruits [52, 70, 71], banana fruits [72], dragon fruits [73], orange fruits [74], and sweet cherry [76].

4.8. Effects on Visual or Sensory Acceptability. Visual or sensory acceptability might be accepted as the aggregate of all parameters. In some of the studies, visual and sensory acceptability of the foods was discussed separately, and it was noted that propolis have a high influence on the acceptability of pomegranate fruit [30], mango fruit [53], papaya fruit [70, 71], banana fruit [72], orange fruit [61], and cucumber fruit [56]. The application of propolis extracts to fruits and vegetables, either by dipping or coating, enhances the sensory quality and microbial durability of the foods. It also contributes to the biochemical and physical characteristics of fruits and vegetables, thereby maintaining the postharvest quality of products during storage. The main disadvantage of the propolis extracts might be as a result of its unique flavor and volatiles, which was noted to cause some alterations on the sensory characteristics of some foods [84].

5. Conclusions

In conclusion, it is clear from the previously discussed information that although the chemical composition of the propolis significantly vary according to the plant source and season, it has a very rich chemical composition, specifically its phenolic compounds, and has a high antioxidant activity. Studies on its antimicrobial and fungicidal effects showed that it is very effective in controlling pathogenic decay. However, the actual mechanism is still not well-understood and further studies are required. Up until now, existing information suggests that the antimicrobial efficacy might be due to its direct influence on the biochemical structures of pathogens or its indirect influence on the biochemical reactions of food products which induce resistant against pathogens. Additionally, published scientific literature suggests that the positive influence of the propolis on the postharvest storability of food products is due to its hydrophobic composites and high phenolic concentration which provides a capability to form biodegradable barrier on fruit surface. This barrier prevents the movement of water and gases through the food surface, which in turn reduce the transpiration and respiration and improve the storability of food products. However, there is still a need to deeply investigate the effects of propolis on the biochemical composition, enzymatic activities, and possible biochemical reactions in food products. This would improve our understanding about the possible mechanism and may lead us to develop industrial biopreservatives from propolis for postharvest applications.

Data Availability

All data used to support the findings of this study are included within the paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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