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Propolis as a natural alternative for food preservation: an integrative review of its antioxidant and antibacterial effects

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ABSTRACT

The presence of several bioactive compounds in propolis has been reported in the literature. These compounds have been described as directly related to their antioxidant and antibacterial activities. Thus, the use of propolis in the food production can be considered as an alternative for food preservation. The present study is an integrative review that was conducted in the following phases: elaboration of the orienting question for the research; literature search; data selection and extraction; data analysis; synthesis of results; and interpretation. For the literature review, some studies were obtained from the following databases: ScienceDirect, Web of Science, Scopus, and PubMed. For the elaboration of the research question, the PICo strategy was used, in which: P refers to the problem (propolis); I refers to the variable of interest (antioxidant and antibacterial effects); and Co refers to the research context (food preservation). Initially, 3421 studies were identified, out of which 15 were used for this review. For the antioxidant and antibacterial effects of propolis on different types of food, it was observed that 80% of the studies evaluated the antioxidant effect, while 33% evaluated the antibacterial effect. Most of these studies showed positive results. Therefore, propolis can be a viable alternative for the industry, as a way to increase food shelf life.

Index terms: antibacterial activity, antioxidant activity, food preservation, food, propolis.

Própolis como alternativa natural para a conservação de alimentos: uma revisão integrativa de seus efeitos antioxidantes e antibacterianos

RESUMO

A presença de vários compostos bioativos em própolis tem sido relatada na literatura. Esses compostos têm sido descritos como diretamente relacionados a suas atividades antioxidantes e antibacterianas. Assim, o uso de própolis na produção de alimentos

Ideias centrais

- Propolis has been applied in food as an additive, edible coatings, and propolis-based film.
- The composition of propolis has various bioactive compounds.
- Propolis is a viable alternative for the industry to increase the shelf life of food.
- The propolis has a synergistic effect when used with other substances.

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pode ser considerado como uma alternativa para a conservação de alimentos. O presente estudo é uma revisão integrativa, que foi conduzida de acordo com as seguintes etapas: elaboração da questão norteadora da pesquisa; seleção e extração dos dados; análise dos dados; síntese dos resultados; e interpretação. Para a revisão de literatura, alguns estudos foram obtidos das seguintes bases dados: ScienceDirect, Web of Science, Scopus e PubMed. Para a elaboração da questão norteadora, a estratégia PICo foi usada, em que: P refere-se ao problema (própolis); I refere-se à variável de interesse (efeitos antioxidantes e antibacterianos); e Co refere-se ao contexto da pesquisa (conservação de alimentos). Inicialmente, 3421 estudos foram identificados, dos quais 15 foram usados para esta revisão. Quanto aos efeitos antioxidantes e antibacterianos de própolis em diferentes tipos de alimentos, observou-se que 80% dos estudos avaliaram o efeito antioxidante, enquanto 33% avaliaram os efeitos antibacterianos. A maioria destes estudos mostrou resultados positivos. Assim, a própolis pode ser uma alternativa viável para a indústria, como meio de aumentar a vida útil dos alimentos.

Termos para indexação: atividade antibacteriana, atividade antioxidante, conservação de alimentos, alimentos, própolis.

INTRODUCTION

The increase of the shelf life of a food product plays a crucial role in the food processing, as this procedure reduces the losses of food and the production of waste. The use of food additives can extend shelf life and improve the sensory characteristics of food, such as taste, color, and others. However, consumers currently prefer food without additives, and a new approach for consumer perception about food products has emerged, which is the the so-called “clean label”. The denomination “clean label” compelled the food industry to communicate whether an ingredient or additive is not present, or if the food has been produced using a more natural production method (Cheung et al., 2016; Asioli et al., 2017; Santos et al., 2019). Thus, alternatives have been searched.

Among the alternatives is the use of natural products in food preservation, highlighting a broad range of biological activities, including antibacterial and antioxidant ones. Among the health benefits, natural products provide fewer side effects than those with chemical preservatives and can be used as natural preservatives in food, as reported by Xing et al. (2021).

In this context, propolis, popularly known as bee glue, is a natural substance, collected by bees from flowers and plants, that is mainly composed of resin, balsam, wax, essential oils, pollen, organic compounds, and bee saliva (Shehata et al., 2020). In addition to using propolis to protect themselves from invaders, bees also use it to control humidity and temperature in the hive (Sarıkahya et al., 2021).

Some studies have proven the presence of several bioactive compounds in propolis, such as flavones, phenolic acids, flavonols, and flavanones, and these compounds are directly related to antioxidant and antibacterial activities. Therefore, the study of the propolis chemical composition is essential to understand its biological activity (Machado et al., 2016; Farag et al., 2021). Furthermore, all types of propolis have antioxidant and antibacterial activity. Still, propolis biochemical structure differs in accordance with some factors, such as botanical and geographical origin, method, and time of collection, which characterizes it as highly variable (Vică et al., 2021).

Literature has been reporting many types of research on the relevance of propolis main characteristics and its use. However, few studies relate its properties to food preservation. Shehata et al. (2020) reported that propolis in food products still needs more investigation. The contemporary trend involves propolis in food manufacturing, trying to meet the expectations and needs of consumers who want to eat food preserved with natural preservatives, which they consider better and safer than synthetic ones.. Such an evaluation should be understood in terms of using propolis as an agent for antibacterial and antioxidative food protection (Pobiega et al., 2019).

The integrative review method has a broad approach that allows of the simultaneous inclusion of data from research of diverse methodology (Whittemore, 2005). The technique consists of data reduction, data display, data comparison, conclusion drawing, and verification. Data reduction consists of grouping similar data in a subgroup classification; thereafter, relevant data are extracted from all primary ones from each subgroup and coded to simplify abstracts and organize data into a data display in a matrix or spreadsheet. Quantitative results are reduced with the emphasis on the main developments in each study, which are related in words to facilitate comparisons with data from the other methodological approaches.

In this context, this integrative review aimed to analyze the primary studies on the antioxidant and antibacterial effects of propolis, highlighting the importance of such reports and their results for food preservation.

METHOD: APPROACHES AND DESCRIPTION

The present study consists of an integrative review that was conducted in the following phases: selection of the research question; literature search; data evaluation; synthesis of data; and interpretation and presentation of the review (Whittemore, 2005). Moreover, PRISMA guidelines (Page et al., 2021) were followed.

For the elaboration of the research question, the PICo strategy was used, in which: P refers to the problem (propolis); I refers to the variable of interest (antioxidant and antibacterial effects); and Co refers to the research context (food preservation) (Peters et al., 2020).

Thus, the following research question was asked: What scientific evidence is related to the antioxidant and antibacterial properties of propolis in food preservation?.

In the search phase, the researches were obtained from the databases ScienceDirect, Web of Science, Scopus, and PubMed, in December 2022. The searches were performed using the keywords “propolis”, “antioxidant activity”, “antibacterial”, “food preservation,” and “food”. These keywords were used to perform the search strategy that reflected the research question, with the boolean operators AND and OR. The following search strategy was used: [(propolis) AND [(antioxidant activity) OR (antibacterial)] AND [(food preservation) OR (food)].

After completing the search, the duplicated articles were removed. The eligibility criteria were established based on the review question. The eligibility criteria were established based on the research question. Thus, for the research selection, the following inclusion criteria were used: studies on the antioxidant and antibacterial properties of propolis in foods; no publication time was applied; published in English, Portuguese, and Spanish. The excluded studies were: types of publication such as literature reviews, conference abstracts, thesis, dissertation, monographs, and book chapters.

After the eligibility stage, data collection for each study was performed according to the objectives of this research. Finally, the presentation of the results was carried out to explore and interpret the selected studies, as well as to observe, describe, and classify the primary data to add knowledge on antioxidant and antimicrobials effects of propolis in food preservation.

The extracted information from the selected researches used a form developed by the authors. Thus, data were collected for the following items: author(s)/year, the origin of propolis, type of use in food, food, the concentration of propolis, purpose, methodology, and main results and conclusions.

RESULTS AND DISCUSSION

The studies found in the search strategy (Figure 1) for the review were described following the PRISMA format (preferred reporting items for reporting systematic reviews and meta-analyses) (Page et al., 2021). Initially, 3421 studies were identified. However, the quantity was reduced to 2680 after the removal of the duplicate articles. After this screening, 53 studies were selected for full reading, applying the inclusion criteria; from this reading, 15 studies were used for the present review.

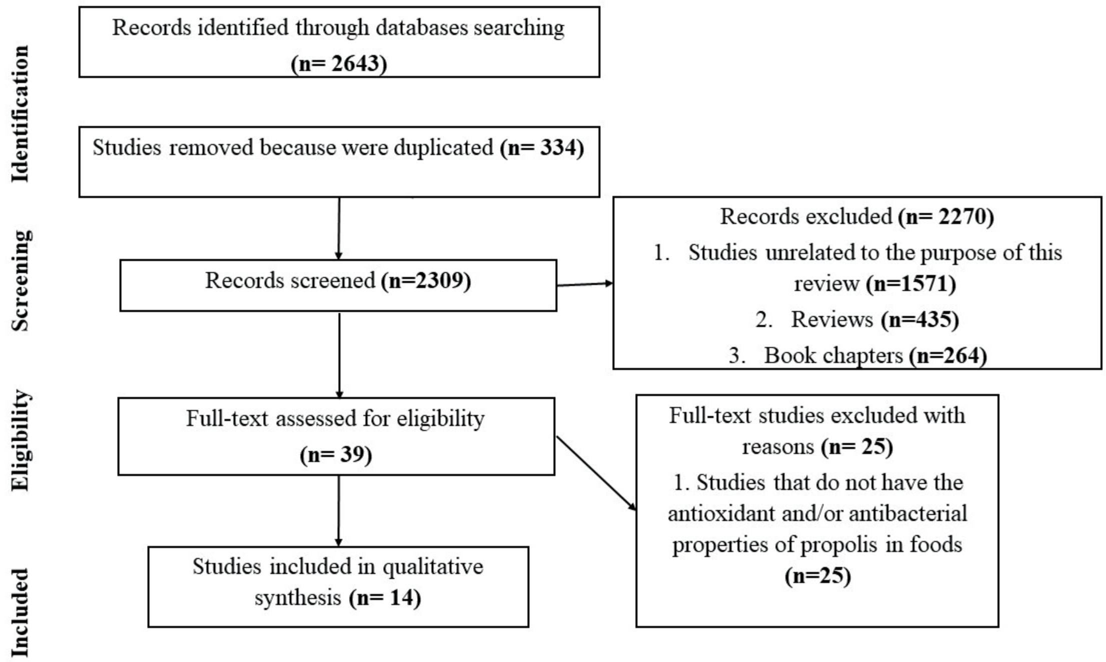

Figure 1. Identification and selection flow of articles included in the integrative review, after database search.

An overview of the included articles is presented in accordance with the following characteristics: author/year, the origin of propolis, type of use in food, and food (Table 1). The articles were published predominantly in English (n = 14); there was also one in Spanish (n=1). Moreover, 90% of this material are publications of the last six years. For the origins of propolis, Spain and Brazil were the countries with the highest number of studies (n =3), followed by Italy (n = 2).

Table 1. Distribution of the selected studies according to author/year, origin of propolis, type of use in food, and food.

Study number	Author/ year	Origin of propolis	Type of use in food	Food
1	Correa et al. (2019)	Brazil (Minas Gerais state)	Edible coating	Gorgonzola-type cheese
2	Habryka et al. (2020)	Poland (Krakow city)	Additive	Honey
3	Khodayari et al. (2019)	Iran (Tehran city)	Packaging film	Vacuum-packed cooked sausages
4	Lopes et al. (2022)	Brazil (Minas Gerais state)	Additive	Red fruit juice
5	Suárez Mahecha & Martínez Bastidas (2020)	Colombia (Bogota city)	Edible coating	Cachama fish nuggets
6	Osés et al. (2015)	Spain (Burgos and Salamanca cities)	Additive	Honey
7	Osés et al. (2016)	Spain	Additive	Honey
8	Pastor et al. (2011)	Spain (Alicante city)	Edible coating	Table grapes
9	Rivero et al. (2020)	Argentina (Gualeguaychu city)	Additive	Gummy jellies
10	Rizzolo et al. (2016)	Italy	Packaging film	Cooked ham slices
11	Santos et al. (2019)	Brazil (Bahia state)	Additive	Probiotic yogurt
12	Spinelli et al. (2015)	Italy	Additive	Fresh fish burgers
13	Ulloa et al. (2017)	Chile (Valparaiso city)	Additive	Craft beer
14	Vasilaki et al. (2019)	France (Saint Jean de Vedas city)	Additive	Non-carbonated beverage
15	Yang et al. (2017)	China (Fuzhou city)	Additive	Orange juice

According to Shehata et al. (2020), propolis has functional compounds which depend on the geographical region; they evaluated the chemical composition, antioxidant, antimicrobial, and cytotoxic activities of propolis sourced from six geographical areas: Egypt, Brazil, Bulgaria, Oman, Saudi Arabia, and China. Thus, these authors observed that the chemical composition showed high variations. They also observed differences for total phenolic and flavonoid contents, and full antioxidant capacities of different propolis samples. Moreover, 33 other phenolic compounds were quantitatively identified in various types of propolis from different geographical regions.

De Groot (2013) reported that there are seven main types of propolis, in accordance with their major compounds and plant origins: poplar, birch, green Brazilian, red, Clusia, Pacific, and the Mediterranean.

The poplar types are found in the temperate regions of Europe and North America, nontropical regions of Asia, China, and New Zealand. The major constituents of this type of propolis are flavones, flavanones, cinnamic acids, and their esters.

Birch propolis also has as main compounds flavones and flavonols. However, these constituents are different from those found in poplar type.

Green propolis from Brazil is mainly composed of prenylated phenylpropanoids, caffeoylquinic acids, and diterpenes.

Red propolis is found in Brazil, Cuba, and Mexico, and its significant compounds are isoflavonoids, neoflavonoids, pterocarpans, and lignans. Clusia propolis is found in Cuba and Venezuela and it is rich in prenylated benzophenones. The Pacific propolis from Okinawa, Taiwan, Indonesia, is rich in *C*-prenyl-flavanones. Mediterranean propolis from Sicily, Greece, and Malta shows diterpenes as major compounds (Lotti et al., 2010; Popova et al., 2012; El-Guendouz et al., 2019). Therefore, the different bioactive compounds resulting from each geographical region provide other effects in food preservation.

Another factor that influences food preservation is the type of application in food. In the present work, we observed that most studies, 67% (n = 10) used propolis as an additive, 20% (n = 3) used it in edible coatings, and 13% (n = 2) used the propolis-based film in foods (Table 1).

Most of the studies related to propolis are used as an additional result of the food industries constant effort to replace synthetic additives by natural ones. Moreover, Ulloa et al. (2017) reported that the food industry interest in using natural antioxidants is due not only to application as preservatives, but also to the potential benefits to human health. Thus, propolis has gained a wide acceptance in many countries for enhancing health and preventing disease.

Films and edible coatings are packaging that have been widely used in food preservation. They are materials with a thin layer composed of proteins, polysaccharides and/or lipids, developed to encapsulate the food, acting like a protective layer, preserving its characteristics for longer (Moreno et al., 2020). Although having the same function, films and coatings are applied differently. After being developed, films are used to involve food products, while coating is a viscous liquid in which food is immersed (Avramescu et al., 2020).

According to Pobiega et al. (2019), there is an increase in studies using propolis extract (PE) on product surfaces or in the form of edible films enriched with PE. For these authors, the advantage of the use of edible films enriched is the assurance of adequate activity of the packaging system, such as the migration of the propolis bioactive components to the food surface. Moreover, Bodini et al. (2013) cited that propolis used directly in foods has a limitation, due to its strong and characteristic odor that can alter the sensory properties of food. Therefore, its use as films and edible coatings is more advantageous.

Yong & Liu (2021) reported that crude propolis usually contains several undesirable substances that are disadvantageous to developing active packaging films and edible coatings. Thus, all five studies that used films or edible coatings (Table 1) used PE. In addition, the authors reported that the functionality of active packaging films and edible coatings is related to the type, geographic origin, extraction method of propolis, the composition of polyphenolic compounds in the extract, and the presence of other bioactive substances. Therefore, depending on these conditions, the active packaging films and edible coatings based on propolis can impact the physical, biochemical, and sensory properties of food during storage.

Meat, fish, fruit, vegetable, fruit juices, and milk are among the foods in which propolis extract is being used. Most of the studies report the use of propolis as an additive in honey (n = 3) and fruit juices (n = 2), in films in meat products (n = 2), and in films in fish products (n = 2) (Table 1).

In honey, the use of propolis aims to provide an alternative to obtain the benefits of propolis, which, due to its low sensory acceptance, is not usually consumed alone. Osés et al. (2016) reported that propolis is hardly accepted by consumers, due to its bitter and astringent flavor. According to Osés et al. (2015), the delicate flavor of honey, together with the sweet and aromatic taste, are attributes that are appreciated by consumers. Thus, researches have been performed on the addition of propolis to honey with the aim to increase the potentially beneficial properties of honey and to increase the acceptance of propolis.

In meat and fish products, propolis has been used as an antioxidant and can confer antioxidative properties during storage (Spinelli et al., 2015; Rizzolo et al., 2016). Moreover, propolis is used in these foods to ensure microbial stability and quality of food during storage. Propolis has been used to reduce or eliminate pathogens that are transferred in food products (Khodayari et al., 2019; Suárez Mahecha & Martínez Bastidas, 2020).

The concentration of propolis used in food influences the results of biological activities in the products. The concentration of PE used in the products is quite variable (Table 2). Studies showed antioxidant and antibacterial effects even at low propolis concentrations.

For the antioxidant and antibacterial effects of propolis on different types of food, it was observed that 80% of the studies (n = 12) evaluated the antioxidant effect, and 33% (n = 5) evaluated the antibacterial effect (Table 2). Among the methodologies used in the studies to determine the antioxidant activity of propolis in foods, the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical capture technique was the most used (8 studies), followed by the 2,2’-azino-bis-3-ethyl benzothiazoline-6-sulfonic acid (ABTS) free radical inhibitory activity (4 studies). For the antibacterial effect, the determination of the minimum inhibitory concentration (MIC) and the agar diffusion were the predominant techniques (2 studies each) (Table 2).

Most studies that evaluated the antioxidant effect of propolis in food had positive results, in comparison with the controls (food without propolis). Santos et al. (2019), in probiotic yogurt with Brazilian red propolis, observed a high antioxidant activity (1.09 mg eq. Trolox/g yogurt), in comparison with samples without PE (0.27 mg eq. Trolox/g yogurt). Moreover, these authors reported that there was a synergistic antioxidant effect of propolis with strawberry pulp because yogurts produced with PE and strawberry pulp showed higher values of phenolic compounds (total phenols and flavonoids) and, consequently, higher antioxidant activity than yogurts prepared with only PE or with strawberry pulp. Osés et al. (2015) also observed that honey added of 0.3% and 0.5% of propolis extract exhibited higher phenolics, flavonoids, and antioxidant activities than honey withou additives.

Ulloa et al. (2017) evaluated different concentrations of propolis in beer and reported that higher PE concentrations provided higher values of bioactive compounds (flavonoids and phenolics) and a greater reduction of the power of radicals, and, as a result, more significant antioxidant activity. These authors highlighted that the incorporation of PE in beer helps with the reduction of oxidation and fortify the phenolic content, which is reduced during the boiling, filtration, bottling, and storage stages of the brewing process.

Table 2. Distribution of selected studies according to concentration of propolis extract (PE), antioxidant and/or antibacterial methodology used and main results of antioxidant and antibacterial effects.

Study number	Concentration of propolis extract	Antioxidant and/or antibacterial methodology	Antioxidant effect	Antibacterial effect
1	5 and 10%	MIC [(a)]	Not evaluated.	The ethanol PE had effect against *Staphylococcus saprophyticus* and *S. equorum*.
2	0.1, 0.3, 0.5, 0.7 and 1.0%	Total antioxidant capacity, DPPH [(b)], ABTS [(c)], FRAP [(d)] and CUPRAC [(e)]	Antioxidant activity increased with the propolis addition. The highest values were obtained in honey with 1.0% of propolis.	Not evaluated.
3	0, 1 and 2%	Standard disc diffusion method	Not evaluated.	The presence of cellulose nanocrystal composites improved the antibacterial activity of films containing poly lactic acid and PE.
4	0.31, 0.46 and 0.61%	DPPH [(b)], ABTS [(c)], and FRAP [(d)]	Antioxidant activity increased with the propolis addition. The highest values were obtained in honey with 0.61% of propolis.	Not evaluated.
5	0.125%	Standard disc diffusion method	Not evaluated.	The ethanol PE had effect against *S. enteritidis*, *L. monocytogenes*, *E.coli*, *Vibrio* sp., and *S.aureus*.
6	0.3-0.5%	TEAC [(f)], BDA [(g)], MIC, and MBC [(h)]	Antioxidant activity increased with the propolis addition.	The propolis honey product had antibacterial activity against *S. aureus*.
7	0.1, 0.3, and 0.5%	ABTS, AOA assay [(i)]	Antioxidant activity increased with the propolis addition.	*S. aureus* and *L. innocua* showed more sensitivity. The most resistant bacterium was *P. aeruginosa*.
8	0.5, 1.0, and 1.5%	DPPH	Coating treatments did not affect the antioxidant capacity of grapes.	Not evaluated.
9	1.41%	ABTS	Antioxidant activity was up to ten times higher than that of similar commercial products.	Not evaluated.
10	0.4%	DPPH	PE added by surface spreading over the polythenate side of paper sheets increased the antioxidant activity during storage.	Not evaluated.
11	0.05%	FRAP, DPPH	Yogurt with PE had better antioxidant activity.	Not evaluated.
12	5%	DPPH	Fish burgers with microencapsulated propolis had antioxidant activity four times higher than that of the control.	Not evaluated.
13	0.005-0.025%	DPPH, ABTS, and FRAP	The greater the concentration of PE in beer increases the antioxidant activity.	Not evaluated.
14	30%	DPPH	The soft drink containing PE showed antioxidant activity higher than that of the control samples.	Not evaluated.
15	2%	DPPH	Propolis was effective in maintaining the antioxidant capacity of orange juice during storage.	Not evaluated.

[(a)]Minimum inhibitory concentration; [(b)]2,2-diphenyl-1-picryl-hydrazyl-hydrate free radical method; [(c)]2,2'-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt radical method; [(d)]ferric reducing ability method; [(e)]cupric reducing ability method; [(f)]Trolox equivalent antioxidant capacity; [(g)]broth dilution assay; [(h)]minimum bactericidal concentration; [(i)] radical-scavenging effect on hydroxyl radicals.

Spinelli et al. (2015), using 5% of microencapsulated PE in fish burgers, observed an increase of four times sequestration activity on DPPH that that of the control. These authors also attributed this result to the phenolic content that also increased. Osés et al. (2016) reported that PE added to honey, even at a concentration as low as 0.1%, increased the antioxidant activity, and that it would enhance the bioactive properties of honey if it was added at higher concentrations. Similar results were observed by Habryka et al. (2020), who reported the highest antioxidant activity value in honey containing the highest propolis concentration. These authors said that this increase of antioxidant activity is due to the content of polyphenolic compounds, including flavonoids and phenolic acids, in which chrysin, pinocembrin, p-coumaric acid, and ferulic acid were present at the highest concentrations.

Lopes et al. (2022) observed that the propolis addition to the red fruit juice increased the content of total phenolic compounds and flavonoids. Moreover, there was an increase of the antioxidant activity, evaluated by the radical scavenging methods DPPH, ABTS, and FRAP, proportionally to the concentration of aqueous extracts of green propolis. There was no negative effect on consumer taste.

Rivero et al. (2020) observed that gummy jellies containing honey and propolis had antioxidant activity up to ten times higher than that of similar commercial products. Moreover, the authors evaluated the antioxidant activity after the *in vitro* digestion. It was observed that after digestion, the product had retention of about 40%, indicating that an actual amount of bioactive components of jellies is preserved.

Vasilaki et al. (2019) obtained soft drink containing PE with antioxidant activity higher than those of the control samples. Besides, these authors evaluated the effect of the temperature (4, 25, and 45 °C) and the time of storage (120 days) on the antioxidant activity of orangea containing PE. These authors observed that the temperature had not a significant effect, and that the antioxidant activity varied between 76.25 and 78.6% at 4, 25, and 45 °C. However, during the storage, there was a reduction of the antioxidant activity.

Rizzolo et al. (2016) evaluated the effect of the application of PE on active paper sheets obtained by either surface spreading (APP) or by incorporating propolis in paper mass (API), in packed slices of cooked ham. In API, when PE was embedded in the paper mass, the interactions between active propolis components and the product were limited during 4 days because there were no changes in the antioxidant properties, comparison with those of the control. However, in APP, when PE was added by surface spreading over the polythene side of paper sheets, interactions between active propolis components and the product increased the antioxidant activity and phenolic compounds with storage. According to the authors, these results are due to the migration of phenolic compounds in the surface of PE, increasing the antioxidant activity.

Yang et al. (2017) compared the propolis emulsion with other chemical food preservatives (sodium benzoate and potassium sorbate), in orange juice, during storage for 35 days. These authors observed that propolis protected the phenolic components in the juice and maintained the antioxidant capacity similar to those of synthetic preservatives.

However, Pastor et al. (2011) could not find a positive effect of PE on grapes. These authors reported that coating treatments with PE did not affect the antioxidant capacity of grapes. Thus, for the authors, although no significant effect of the PE addition was observed on the preservation of grape quality, its incorporation in the edible coatings, provided the enrichment of health characteristics of the coated product.

The antibacterial activity is one of the essential characteristics of PE, which allows of its use in the prophylaxis of various diseases. For the antibacterial effect in foods, five studies had positive results. Correa et al. (2019) evaluated the antibacterial effect of propolis in cheese and observed inhibition of *Staphylococcus saprophyticus* and *S. equorum*. These authors reported that the leading cause of this inhibition is that propolis has a greater antibacterial activity against gram-positive bacteria than against gram-negative ones. Osés et al. (2016) reported that the propolis addition to honey increased the antibacterial activity against *S. aureus* and *L. innocua*. Moreover, a synergic effect was observed between PE and honey because higher halo inhibition zones were found in all products than in honey or PE alone. Osés et al. (2015) confirmed that the high concentration of propolis in honey increases

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the antibacterial effect. These authors also reported that propolis not only helps in preserving food, but also acts in the organism, treating infections.

Suárez Mahecha & Martínez Bastidas (2020), using PE in an edible coating applied to cachama fish nuggets (*Piaractus brachypomus*), reported antibacterial activity against the bacteria *Salmonella enteritidis* ATCC 25923, *Listeria monocytogenes* ATCC 13076, *E. coli* ATCC 25922, *Vibrio* sp., and *Staphylococcus aureus* ATCC 25923.

In turn, Khodayari et al. (2019) did not observe the antibacterial effect in films containing PE with polylactic acid. These authors attributed this result to the poor interfacial adhesion between the hydrophilic PE and the hydrophobic polylactic acid, leading to low antimicrobial properties. However, the antibacterial activity of films with PE and polylactic acid was improved by adding cellulose nanocrystal-based composites. The increase of antibacterial activity resulted in the compatibility of hydrophobic polylactic acid, enhanced with hydrophilic cellulose. Thus, it is important to evaluate the interactions of the compounds of the films to obtain the best effects of propolis on the antibacterial activity.

In addition to the antioxidant and microbial activities determination, other analyses were performed for foods added with propolis. Thus, the aim of the studies and their main results are summarized, as follows (Table 3).

One of the most evaluated aims in the studies was to verify the effect of propolis on the sensory acceptance, which was studied in six studies (Table 3). According to Spinelli et al. (2015), propolis has a limited application to food products because of its strong and unpleasant taste and its odor, which generally compromise the food acceptability.

Correa et al. (2019) evaluated the antimicrobial effect of Brazilian green propolis on microorganisms on the surface of cheese and concluded that propolis could be safely used at of 5.0% concentration on the cheese surface. Furthermore, these authors related that the taste and odor were not negatively affected at this concentration, and that the growth of microorganisms was completely inhibited.

Habryka et al. (2020) enriched honey with propolis and reported that the occurrence of main changes on the sensory characteristics. According to the authors, the color of the product underwent a reduction of brightness, clarity, uniformity, and cloudiness. For flavor, there was an increase in the perception of waxy, molasses, and off-flavor. Moreover, these authors reported that there was an increase of acidity and bitterness, with a persistent aftertaste. Finally, there was a decrease of smoothness and meltability, and an increase of viscosity and adhesion in the texture evaluation.

Thus, as the propolis addition can negatively affect the sensory acceptance, it is essential to determine the best concentration to add it to foods, without damaging the acceptance. Osés et al. (2015) determined the maximum concentration of propolis extract that could be applied to honey without affecting the sensory acceptance. These authors reported that concentrations from 0.3 to 0.5% propolis would be acceptable in honey, depending on the strength of propolis flavors.

Rivero et al. (2020) evaluated the sensory acceptance of gummy jellies containing honey and propolis. These authors reported that more than 90% of consumers "gave liking to categories", having the product a good global acceptance. The authors reported that another positive result was that the addition of propolis delayed the fungal growth during storage for 90 days. These results showed that PE prevents the growth of microorganisms and has a synergistic effect when used with honey.

Rizzolo et al. (2016) reported that although there was an increase of antioxidant properties in packed slices of cooked ham on active paper sheets, obtained by surface spreading (APP), the composition of the volatile compounds indicated lipid and nonlipid oxidation reactions. Moreover, through the sensory triangle test, it was possible to find the volatile pattern and volatile composition changes at the end of 4-day storage.

Table 3. Distribution of selected studies according to purpose and main conclusions.

Study number	Study purpose	Main conclusions
1	To evaluate the antimicrobial effects of the ethanol extract of green propolis (EEP) on the microorganisms found on the surface of gorgonzola-type cheese, and to evaluate the effects of EEP on the sensory characteristics.	The EEP showed potential to be used in gorgonzola-type cheese. EEP had antimicrobial effect on bacteria and yeasts. The sensory attributes were not largely affected.
2	To analyze honey enrichment from propolis in the content of bioactive compounds, antioxidant potential, as well as sensory characteristics.	Honey with propolis extract showed high content of antioxidant compounds. However, the amount of additive used is strongly dependent on changes of the sensory characteristics.
3	To determine the use of the poly (lactic acid) composite films combined with cellulose nanocrystal-based composites (CNC), *Tanacetum balsamita* (L.) essential oil (TBE), and propolis ethanolic extract (PEE), in vacuum-packed cooked sausages, during the storage	PEE and TBE had a synergistic antibacterial effect. The use of PLA/CNC composite matrix with antimicrobial agents, such as PEE and TBE, might be an alternative for active packaging development.
4	To obtain a beverage supplemented with Brazilian green propolis	The propolis addition to red fruit juice increased the total phenolic content and flavonoids, and enhanced the antioxidant activity.
5	To evaluate the use of extracts of propolis (PE), essential oil of laurel and chitosan applied to edible coatings, for their effects on the antibacterial activity in meat food.	The substances had a synergistic antibacterial effect. The use of substances in the edible coatings may be an alternative for the preservation of meat foods.
6	To determine the maximum concentration of propolis extract that can be mixed with honey, without affecting the sensory acceptance, and to verify phenolics, flavonoids, antioxidant and antibacterial activities.	The manufacturing of a food product made with a dark and strong honey and 0.3-0.5% propolis is commercially viable.
7	To obtain a food product made with honey and propolis, to enhance its antimicrobial, antioxidant and anti-inflammatory properties.	PE added to honey, at a concentration as low as 0.1%, is able to increase the antimicrobial, antioxidant and anti-inflammatory properties in food.
8	To determine the effect of hydroxypropylmethylcellulose incorporated with PE on the development of the physico-chemical properties, respiration rate, and microbial counts of table grape, during 22 storage days at 1–2 ◦C.	PE increased the luminosity of the grapes. No significant effect of the PE was observed on the preservation of grape conservation.
9	To develop healthy and palatable gummy jellies containing honey and PE	The gummy jelly had good sensory acceptance. Moreover, offered a high bioaccesible antioxidant activity. The addition of propolis delayed the fungal growth during storage.
10	To evaluate the application of PE on active paper sheets obtained by either surface spreading (APP), or by incorporating propolis in paper mass (API), in packed slices of cooked ham	Increase of antioxidant properties of packed slices of cooked ham on active paper sheets obtained by APP. The volatile compound compositions indicated lipid and nonlipid oxidation reactions.
11	To evaluate the quality parameters in probiotic yogurt produced with Brazilian red propolis, to replace potassium sorbate used in conventional yogurt (CY), during 28 days of storage.	Red propolis showed to be an excellent natural additive. The probiotic bacteria have more stability during storage than that of CY.
12	To improve the sensory properties and to evaluate the total phenolic compounds and the antioxidant activity in fish burgers with microencapsulated propolis.	Final fish product with good acceptability. Proper tests on burgers showed an effective increase of both phenolic contents and antioxidant activity.
13	To investigate the potential for increasing the bioactive compounds and antioxidant activity of a craft beer, by adding PE during cold maturation without affecting the physicochemical parameters	The incorporation of PE increased the bioactive compounds and antioxidant activity in beer, without altering the physicochemical parameters of golden ale beer.
14	To add PE in a noncarbonated orange soft drink, aiming to the replacement of artificial preservatives and the increase of the product bioactvity.	PE confers the advantage of storage even at environmental temperature, without affecting the polyphenol content and antioxidant activity.
15	To determine whether propolis, without alcohol, can serve as an alternative and nonsynthetic preservative of orange juice	Propolis emulsion is an alternative, nonsynthetic preservative of orange juice.

Spinelli et al. (2015) used microencapsulation at 5% propolis, to improve the sensory acceptance of fish burgers. These authors reported that adding 5% of spray-dried propolis to a proper fish burger formulation showed a positive sensory evaluation (overall quality scores of 6.00 and 6.50, for raw and cooked fish burgers, respectively).

For the quality parameter color, Pastor et al. (2011) observed changes in the color of grapes coated with edible coatings containing PE. These authors observed that PE increased the luminosity of the fruit, as a result of greater film opacity, which is considered positive. Although there were changes in the color, no effect of the PE was observed on the preservation of grape quality during storage.

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Propolis also can provide beneficial effects to the growth of beneficial bacteria in probiotic foods. The PE also showed an effect on the maintainance of the characteristics of probiotic microorganisms in yogurt, during 28 days of storage. Santos et al. (2019) reported that conventional yogurt containing potassium sorbate showed a drastic reduction of the population of lactic acid bacteria, after 7 days of storage. However, yogurt with Brazilian red propolis PE preserved these bacteria. According to these authors, the reduction of lactic acid counts in commercial yogurt is attributed to the chemical additive potassium sorbate. Thus, the red propolis did not have negative interactions with the lactic acid bacteria, increasing the probiotic potential of yogurt.

Propolis inhibits the growth of spoilage bacteria, providing an advantage to the food to which it is added. Vasilaki et al. (2019) reported that noncarbonated orange soft drinks containing PE had high phenolic contents and remarkable microbiological stability. In addition, the PE inhibited the growth of bacteria, yeasts, and molds in the stored drinks. Thus, the beverage containing PE, a bioactive product, could be mantained at a wide temperature range, for up to 120 days, without showing quality and microbiological deterioration.

Ulloa et al. (2017) reported that PE used in golden ale beer did not alter the physicochemical parameters of the original extract, real extract, and alcohol contentd. Thus, the authors concluded that the PE has the potential to improve the stability and shelf-life of beers, without the incorporation of artificial preservatives.

Yang et al. (2017) evaluated the propolis emulsion as a substitute to chemical food preservatives in orange juice during storage for 35 days. These authors reported that propolis emulsion inhibited the growth of bacteria and the ascorbic acid degradation. Moreover, the orange juice pH value and titratable acidity were maintained by propolis emulsion during storage. Thus, these authors concluded that propolis emulsion propolis could improve the quality of orange juice in comparison with other chemical preservatives.

Another essential feature of propolis is the synergistic effect it shows, when it is in contact with other substances. Propolis can be used in films and foods in combination with other antimicrobial agents. Khodayari et al. (2019) observed a synergistic antibacterial effect between *Tanacetum balsamita* (L.) essential oil (TBE) and propolis ethanolic extract (PEE). These authors concluded that films of polylactic acid-containing cellulose nanocrystal-based composites (2%), TBE (2%), PEE (2%) showed better results for an antibacterial activity in sausage packaging. Suárez Mahecha & Martínez Bastidas (2020) used PE in an edible coating applied to cachama fish nuggets (*Piaractus brachypomus*), and they observed a synergistic antibacterial effect of ethanol extracts of propolis (PE) (0.125%), essential oil of laurel (0.625%), and chitosan (2.5%). Besides, this synergic effect can occur with substances present in the food itself. Osés et al. (2016) reported that the antimicrobial activity of the combined products showed synergic effects, resulting in higher results than those of the base honey and propolis extracts. Thus, the authors concluded that honey enriched with small amounts of propolis extracts are a promising functional food.

CONCLUSIONS

This integrative review assessed primary studies on the antioxidant and antibacterial properties of propolis, and the importance of these biological properties for food preservation. Propolis has been applied to various types of food, mainly as an additive in honey, used as films in meat products, and used as an additive and as films in fish products.

In the present review, Brazil and Spain are the countries with the highest number of studies on the use of propolis in food, followed by Italy. Among these foods are meat, honey, fish, fruit, vegetable, fruit juice, and milk. In these foods, propolis is added as additive, edible coatings, and propolis-based films, aiming to extend the food shelf life.

The search for natural sources of antioxidants has been motivated by the understanding that propolis plays a crucial role in the prevention of chronic diseases. Thus, in the composition of propolis, the presence of various bioactive compounds was observed as directly related to the antioxidant and antibacterial activities.

Sensory acceptance was also assessed in the mentioned studies because propolis has limited applications to food products, due to its strong and unpleasant taste, as well as its odor, which generally compromises food acceptability. Moreover, the studies have been performed to evaluate the synergistic effect of propolis with other substances.

Based on the survey carried out, it is possible to suggest that future researches deepen the knowledge about propolis and its applications. More comprehensive investigation into the chemical composition of propolis from different regions of the world can provide valuable insights for regional variations, and for the relationship between composition and therapeutic benefits. Furthermore, well-designed clinical studies are needed to validate the antioxidant effects of propolis in humans.

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