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Ethanolic Propolis Extract as a Natural Antifungal Preservative: Impact on the Physicochemical, Microbial, and Sensory Properties of Cupcakes

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Abstract

The widespread use of food additives worldwide has raised concerns regarding their potential adverse effects. Given the increasing demand for natural antimicrobial compounds, propolis extract can serve as a safer alternative to synthetic preservatives. This study aimed to investigate the effect of ethanolic propolis extract (EPE), a natural antimicrobial agent, on the physicochemical, microbial, and sensory properties of cake. For this purpose, EPE at concentrations of 0.15%, 0.30%, 0.45%, and 0.60% was incorporated into cake batters, and the quality characteristics of the cakes were evaluated. The results indicated that incorporating EPE at levels above 0.30% increased batter density. Additionally, the presence of EPE and its increased concentration resulted in greater batter consistency. The inclusion of EPE in the cake formulation also contributed to moisture retention during baking and storage (two weeks). However, all cake samples exhibited a decline in moisture content over the storage period, with the control sample (without EPE) experiencing the most significant moisture loss. The cakes containing 0.15% and 0.30% EPE demonstrated the highest specific volume and porosity, as well as the lowest firmness (measured two hours after baking) compared to other formulations. Notably, all EPE-containing samples maintained a softer texture than the control throughout storage. The presence of EPE also influenced the crust color of the cakes, as higher EPE concentrations resulted in decreased $L*$ and $a*$ value and an increased $b*$ value, leading to a darker appearance. Sensory evaluation revealed that cakes with 0.15% and 0.30% EPE exhibited similar characteristics in terms of shape, form, hardness, softness, chewability, upper surface properties, and porosity. Although their flavor and aroma scores were deemed acceptable by sensory panelists, they were slightly lower than those of the control sample. Overall, cupcakes containing 0.15% and 0.30% ethanolic propolis extract were identified as the optimal formulations, with 0.30% EPE offering the best balance between antifungal efficacy, physicochemical quality, and sensory acceptability, making it a promising natural preservative for bakery products. Therefore, EPE has the potential to be utilized as a natural additive with antifungal properties in cake formulations.

Keywords: Antifungal effect, Cake, Natural preservative, Propolis extract

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Introduction

In 2023, Ireland led the European cake and pastry market with a per capita consumption of 24.52 kg, followed by France at 17.67 kg and the United Kingdom at 17.15 kg. Countries such as Spain, Slovakia, and Italy also showed significant consumption levels, exceeding 16 kg per capita. Meanwhile, Poland, the Czech Republic, and Scandinavian countries like Sweden and Denmark had lower consumption volumes, ranging between 6 and 7 kg per capita. In the United States, the per capita volume in the *Preserved Pastry Goods & Cakes* segment of the food market was projected to increase steadily between 2025 and 2030, rising by a total of 1.5 kilograms (+18.09%). After eight consecutive years of growth, the average per capita volume is expected to reach 9.8 kilograms by 2030, marking a new peak. In 2022, the annual per capita consumption of biscuits and industrial sweets (including cakes, muffins, cookies, and wafers) by Iranians was 10 kg per person (reportlinker).

Microbial spoilage is the primary limiting factor affecting the shelf life of bakery products with medium to high moisture content. Therefore, controlling microbial spoilage, particularly mold growth, is crucial for the economic sustainability of the flour and bakery industry. The most practical, common, and cost-effective approach is the use of chemical preservatives such as propionates and sorbates, which are directly incorporated into product formulations (Pyrgioti, Graikou, Cheilari, & Chinou, 2022). The rising incidence of foodborne diseases, along with the associated social and economic challenges, has highlighted the need for healthier food production and the use of novel antimicrobial compounds. Concerns regarding certain chemical preservatives and negative consumer reactions toward their use have led to an increased interest in natural preservatives as an alternatives. Consequently, both manufacturers and consumers have turned their attention towards plant essential oils. The antimicrobial properties of these substances against a wide range of bacteria, yeasts, and fungi have been well documented (Tajik, Nateghi, & Berenji, 2017). The significance of essential oils lies not only in their ability to impart aroma and flavor to food but also in their phenolic compounds, such as eugenol, carvacrol, and thymol, which exhibit antimicrobial effects. The higher the phenolic content in essential oils, the stronger their antimicrobial properties (Hosseinzadeh & Shirazinejad, 2019). Essential oils and extracts derived from medicinal plants are emerging as new natural preservatives with potent antimicrobial, anticancer, and antioxidant properties, making them highly effective in protecting both raw and processed foods (Ike, Emeka-Ike, & Ogwuegbu, 2020). Propolis, one of the most important bee products, is recognized as a natural antibiotic and a potential alternative to industrial antibiotics, contributing to the reduction of unnecessary antibiotic use. Flavonoids constitute the majority of the resinous fraction of propolis and are primarily responsible for its antioxidant, antibacterial, antiviral, antifungal, anticancer, and anti-inflammatory properties (Garzoli *et al*., 2023).

The main components of propolis include aromatic acids (such as cinnamic acid, caffeic acid, and ferulic acid), aromatic esters (e.g., ether esters of cinnamic and caffeic acids), and volatile compounds (such as geraniol, nerol, farnesol, and beta-eudesmol) (Abtahi, Mehraban, Bagheri, Fathi Najafi, & Islami, 2022). Additionally, it contains aromatic compounds (e.g., vanillin), hydrocarbons (such as eicosane, tricosane, and pentacosane), steroids (e.g., cholestanol, fucosterol, and stigmasterol), enzymes (such as α-amylase and β-amylase), flavonoids (e.g., pinocembrin, chrysin, galangin, apigenin, and kaempferol), acids (such as palmitic acid, melissic acid, and cerotic acids), as well as micro- and macronutrients (e.g., calcium, potassium, magnesium, sodium, zinc, iron, manganese, aluminum, and chlorine). Furthermore, it contains vitamins (such as B1, B2, B6, C, and E) and essential oils, which are primarily represented by monoterpenes and sesquiterpenes (Garzoli *et al*., 2023). However, limited research has been conducted on the impact of propolis on the physicochemical, sensory, and microbial properties of bakery products, particularly cakes. Therefore, this study aims to investigate the effects of ethanolic propolis extract (EPE) on the quality characteristics of cakes and explore its potential as a natural preservative. The results of this research could contribute to enhancing the quality and safety of bakery products and offer a practical alternative to synthetic preservatives in the industry.

Materials and Methods

The raw materials, including wheat flour, white sugar, liquid vegetable oil, fresh eggs, vanilla, and baking powder, were purchased from the local market. Propolis powder and chemicals required for the cake tests were purchased from reputable Iranian companies.

Lyophilized strains of *Aspergillus niger* (ATCC 9142), *Rhizopus stolonifer* (ATCC 14037), and *Penicillium expansum* (ATCC 58619)—the primary molds responsible for spoilage in cakes and bakery products—were purchased from the Regional Center for Bacteria and Industrial Fungi Collection of Iran. The lyophilized strains were inoculated into Potato Dextrose Broth (PDB) and then surface-cultured on Potato Dextrose Agar (PDA). The cultures were then incubated at 25°C for three days and stored at 4°C until use. Molds were cultured on slanted PDA medium at 25°C for 4–7 days until sporulation occurred. The spores were then collected from the surface of the PDA medium by adding sterile Ringer's solution. Finally, the spore count was determined using a hemocytometer under a microscope, and a suspension containing 10^5 spores/ml was prepared (Rezaei Boroojerdi, Habibi Najafi, Hosseini, & Karazhyan, 2018).

The MIC and MFC of propolis extract were determined using the microdilution method. Serial dilutions of propolis extract were prepared in PDB medium, starting from an initial concentration of 300 mg/ml. Then, 100 µL of each dilution was added to a 96-well microplate, followed by adding 95 µL of PDB medium and 5 µL of the mold spore suspension. A negative control contained only PDB medium and the mold strain. A positive control included PDB medium, the mold strain, and potassium sorbate as antifungal agent. The microplates were incubated at 25°C for 72 hours. The lowest concentration of propolis extract that completely inhibited mold growth (showing no turbidity) was recorded as the MIC. To determine the MFC, 100 µL from wells where no mold growth was observed was plated onto PDA medium. The plates were incubated at 25°C for 3–5 days, and the lowest concentration of propolis extract that resulted in 99.9% inhibition of mold growth was recorded as the MFC (Olamaeian, Kouhdar, & Hosseini, 2022).

The cake batter was prepared using 312 g wheat flour, 233 g water, 242 g sugar, 112 g oil, 6.7 g baking powder, 1.1 g vanilla, 140 g eggs, and propolis extract at concentrations of 0, 0.15, 0.30, 0.45, and 0.60% (based on flour weight). Oil, powdered sugar, and eggs were mixed using an electric mixer at 128 rpm for 6 minutes to form a creamy, aerated mixture. Water was then added, and mixing continued for 4 minutes. Baking powder and vanilla were combined with the flour and gradually incorporated into the batter, followed by the addition of propolis extract. The final batter was poured into cupcake molds and baked at 170°C for 20 minutes. After cooling, the cakes were packaged and stored at room temperature for subsequent physicochemical and microbiological analyses (Tajik *et al*., 2017).

Evaluation of Physicochemical Properties of Wheat Flour

The chemical composition of wheat flour was measured based on standard methods outlined by the American Association of Cereal Chemists (AACC, 2005).

Dough Density and Consistency

The specific weight of the dough was measured according to the method of Pasukamonset *et al.* (2018). In this method, the weight of a specific volume of dough was measured in a designated container, and then the weight of an equal volume of water at the same temperature was used to divide the dough weight. The dough consistency was measured using a Bostwick consistency meter. This device consists of a rectangular or semi-cylindrical chamber with two compartments (small and large). Dough is placed in the small compartment, and after releasing a specialized blade between the two compartments, the distance traveled by the dough during 30 seconds was recorded as the consistency (Aleman, Morris, Prinyawiwatkul, Moncada, & King, 2022).

Evaluation of Physicochemical, Sensory, and Microbiological Properties of Oil Cake

According to the method of Pasukamonset *et al*. (2018), the moisture content of powdered samples was measured at 2 hours, 1 week, and 2 weeks after baking using a moisture analyzer. To measure the specific volume of the cake, the canola seed displacement method was used, following AACC Standard 72-10 (AACC, 2005). The color analysis of the cake crust was conducted 2 hours after baking using a colorimeter (Minolta CR-400, Konica Minolta, Japan), determining the three-color indices: L*, a*, and b* (Hassan, Fahmy, Magdy, & Hassan, 2020). Texture evaluation was performed using a texture analyzer (TA Plus, UK) at 2 hours, 1 week, and 2 weeks after baking. The maximum force required to penetrate a cylindrical probe (2 cm diameter and 3/2 cm height) at a speed of 60 mm/min from the center of the muffin was calculated as the firmness index (Salem, El-Zayet, Rayan, & Shatta, 2024). The sensory characteristics of the product were evaluated by 12 trained panelists, based on attributes such as form and shape, upper surface (crust), lower surface, porosity and crumb structure, texture firmness and softness, chewability, and taste (smell and flavor) using a 5-point hedonic scale. In this test, the ratings were: 5 (excellent), 4 (good), 3 (average), 2 (bad), and 1 (very bad) (Ahmed, Ragab, Gadallah, Alhomaid, & Almujaydil, 2024). The enumeration of mold and yeast, as well as the total mesophilic microorganism count, were performed according to the international standard ISO 4833-1, at time intervals of 1, 7, 14, and 21 days after baking.

Statistical Design

The experiments were conducted using a completely randomized design with different concentrations of ethanolic propolis extract (0, 0.15, 0.30, 0.45, and 0.60%). For variables affected by storage time, a separate statistical analysis was carried out to evaluate differences among storage days within each treatment as well as differences among treatments at each storage day. Mean comparisons were performed using Tukey's multiple range test ($P < 0.05$).

Results and Discussion

Antifungal Properties of Propolis Against mold spoilage of Cake in Laboratory Conditions

In this study, the antifungal activity of ethanolic propolis extract was evaluated against *Aspergillus niger*, *Rhizopus stolonifer*, and *Penicillium expansum*, which are the primary molds responsible for spoilage in cakes. The microdilution method was used to assess the antifungal properties. The minimum inhibitory concentration (MIC) of the ethanolic propolis extract against *Aspergillus niger*, *Rhizopus stolonifer*, *and Penicillium expansum* was 125 µg/ml, 62.5 µg/ml, and 62.5 µg/ml, respectively. The minimum fungicidal concentration (MFC) was 250 µg/ml, 125 µg/ml, and 125 µg/ml, respectively (Table 1). Ethanol 80% was used as a control solvent and did not affect the fungi studied. The minimum inhibitory concentration of ethanol 80% was higher than 8000 µg/ml. Shokri, Katiraee, Fatahinia, & Minooeianhaghighi, (2017) examined the chemical composition and antifungal potential of Iranian propolis against *Candida krusei* strains. They reported that the minimum inhibitory concentration (MIC) and minimum fungicidal concentration (MFC) of Iranian propolis were 2-20 mg/ml and 4-25 mg/ml, respectively. Gucwa, Kusznierewicz, Milewski, Van Dijck, & Szweda, (2018) reported the minimum fungicidal concentration (MFC) of ethanolic propolis extract from Poland against a group of 69 clinical *Candida albicans* isolates was in the range of 1.25% to 0.08% (v/v). The results of Fernández-Calderón *et al.* (2021) showed that the ethanolic propolis extract from Spain exhibited antifungal activity against *Candida glabrata* isolates, with a minimum inhibitory concentration (MIC) of approximately 0.2% (v/v) and a minimum fungicidal concentration (MFC) of 0.4% (v/v). Papp *et al.* (2021) collected propolis samples from four regions in Hungary: Csikóstőttős, Héhalom, Somogybabod, and Szolnok. The Szolnok, Héhalom, and Csikóstőttős samples exhibited stronger antifungal activity, with their minimum inhibitory concentration (MIC) and IC50 values reported ranged between 100-200 µg/ml and 72-134 µg/ml, respectively. Although the Somogybabod sample was significantly weaker than the other propolis samples, its inhibitory effect on fungal cell growth at 400 µg/ml was not less than 18%. The results of these researchers are consistent with our findings. Zampini, Salas, Maldonado, Simirgiotis, & Isla, (2021) showed that these extracts exhibited significant antibacterial effects, particularly against Gram-positive bacteria such as *Staphylococcus aureus*, with minimum inhibitory concentration (MIC) values ranging from 10 to 100 µg/mL. In contrast, the extracts were less effective against Gram-negative bacteria, showing MIC values between 400 and 1600 µg/mL. Additionally, the propolis extracts demonstrated antifungal activity against dermatophytes like *Microsporum gypseum*, *Trichophyton mentagrophytes*, and *Trichophyton rubrum*, with MIC values between 16 and 125 µg/mL. The primary compounds responsible for this antifungal activity were identified as two chalcones, DHC and DHMC, which exhibited MIC values between 1.9 and 2.9 µg/mL. Vică *et al.* (2022) reported that the minimum inhibitory concentration (MIC) of ethanolic propolis extracts from the Romanian against *Candida albicans*, *Candida krusei*, *Candida tropicalis*, *Candida glabrata*, and *Aspergillus fumigatus* ranged from 1.56 mg/mL to 3.12 mg/mL. The antimicrobial activity of nine aqueous propolis extracts from various Romanian regions reported by Heghedűş-Mîndru *et al.* (2023) was evaluated against six bacterial strains commonly associated with cereals. They employed the disk diffusion method to measure the diameters of inhibition zones, which ranged from 16 to 29 mm, indicating varying degrees of antimicrobial efficacy. Notably, sample S1 from Transylvania exhibited the most potent inhibitory effect, particularly against *Bacillus cereus*.

Table 1- Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC) of ethanolic propolis extract against the main spoilage molds in cakes (µg/ml)

Mold	MIC	MFC
Aspergillus niger	125	250
Rhizopus stolonifer	62.5	125
Penicillium expansum	62.5	125

Physical and Chemical Properties of Wheat Flour

Table 2 presents the physical and chemical properties of wheat flour with an extraction rate of 75%. According to the results, the flour used in the cake formulation contained 9.84% moisture, 8.58% protein, 1.42% fat, 0.49% ash, and 29.71% wet gluten.

Table 2- Physical and chemical properties of wheat flour

Properties	Value (%)
Moisture	9.84
Protein	8.58
Fat	1.42
Ash	0.49
Wet Gluten	29.71

Dough Characteristics

Density

With an increase of more than 0.30% propolis extract in the cake dough formulation, the density significantly increased (P<0.05) (Fig. 1). The highest value for this parameter was observed in the samples containing 0.45% and 0.60% propolis extract, while the lowest value was found in both the control sample and the samples containing 0.15% and 0.30% propolis extract.

The density of cake dough and similar products indicates the presence of air bubbles in the dough and its proper aeration, as well as the retention of gas bubbles during the dough preparation process, particularly in the mixing stage. In this way, the more efficiently air bubbles are incorporated into the dough, the lower the density, resulting in a lighter dough (Salem *et al*., 2024). Scanlon & Koksel (2024) reported that proper processing and aeration of cake dough led to the better incorporation and distribution of air bubbles, which in turn results in a reduction in dough density. The decrease in dough density plays a crucial role in increasing the volume, porosity and reducing the firmness of the internal texture of cakes. As the results of this study showed, at higher levels of propolis extract (0.45% and 0.60%), the dough density increased. It is likely that the use of propolis or bee pollen, by reinforcing the gluten network of the dough and strengthening this network, causes an increase in dough density through disruption of the aeration process. Tahmouzi *et al.* (2023) stated that when biopolymer compounds, such as various gums, are used in food formulations at appropriate levels, they can improve dough aeration by preventing the aggregation of gas bubbles. This is due to the formation of a thick layer on the surface of the bubbles, which stabilizes the gas bubbles and keeps them separated, ultimately increasing dough density and, consequently, volume and porosity. Milinčić, Kostić, Stanojević, & Pešić, (2024) reported that the inclusion of propolis or bee pollen extract in the formulation of oil-based cakes led to a reduction in the spreadability of air bubbles during the mixing process and the air bubbles generated from the activity of baking powder. As a result, dough density increased, and cake volume decreased.

Consistency

Incorporation of propolis extract at all levels in the cake dough formulation increased consistency. An upward trend in consistency was observed from the control sample to the sample containing 0.60% propolis extract. The Bostwick value is inversely related to dough consistency, with a decrease in this value indicating an increase in dough consistency. The control sample had the lowest consistency, while the sample containing 0.60% propolis extract exhibited the highest consistency compared to the other treatments (Fig. 2). Dough consistency refers to the time it takes for fluids to flow. It directly impacts product properties such as moisture content, texture firmness, porosity, and shelf life. Low dough viscosity allows air bubbles to easily rise to the surface and burst. Additionally, air bubbles trapped in the dough may not remain during baking, leading to the collapse of the cake structure in the oven. Several factors, including increased water absorption, gel formation, the strengthening of the three-dimensional network of the dough, and emulsion stability, contribute to enhancing the consistency of cake dough. Milinčić *et al.* (2024) reported that the inclusion of propolis in cupcake formulations helped strengthen the gluten network in the dough. At higher concentrations of propolis, both dough consistency and viscosity increased significantly, which, however, had technologically destructive effects on the texture of both the dough and the resulting cake.

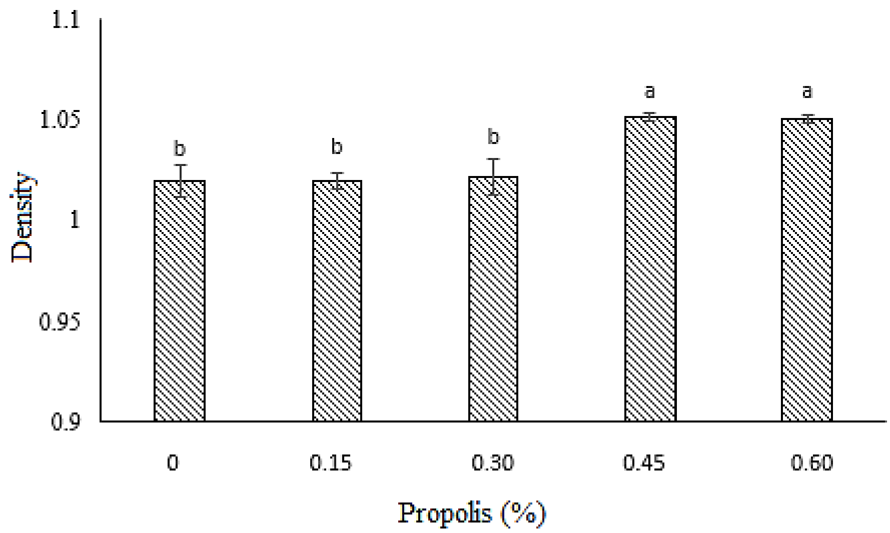

Fig. 1. Effect of different levels of propolis extract on the density of cake dough
Like letters are not statistically significant at the P<0.05 level.

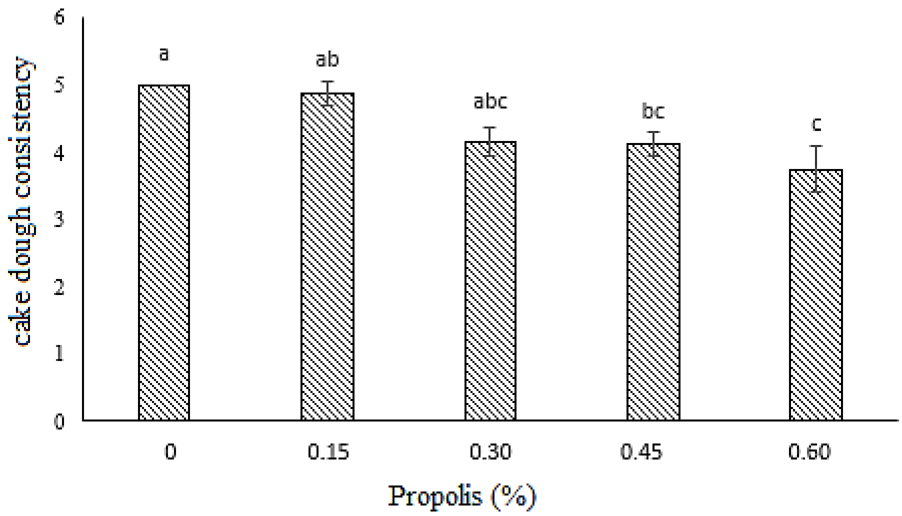

Fig. 2. Effect of different levels of propolis extract on cake dough consistency
Like letters are not statistically significant at the P<0.05 level.

Physical and Chemical Properties of Cake

Moisture

The moisture content of cake samples containing more than 0.15% propolis extract was significantly higher ($P<0.05$) than that of the control sample within 2 hours after baking. The lowest moisture content was observed in the control sample, while the highest moisture content was found in the sample containing 0.60% propolis extract. The results indicated that the samples containing 0.45% and 0.60% propolis extract had the highest moisture content, both at 1 and 2 weeks after baking (Fig. 3). Moisture content in all cake samples decreased over the 2-week storage period, with the control sample showing the greatest moisture loss compared to the other formulations. The optimal consumption time for baked products is within 3 days after production; however, the shelf life of baked goods can be extended by using moisture-absorbing compounds (Pyrgioti *et al*., 2022). Based on the results, propolis extract and its increased concentration helped retain moisture in the samples compared to the control sample, both during the baking process and throughout the 2-week storage period. This highlights the hygroscopic properties of propolis extract. Tahmouzi *et al*. (2023) also reported that hydrocolloid compounds have a gelling property and can trap free water in the environment, thereby increasing the moisture content of the sample and preserving it during storage. Compounds with the ability to form gels create a three-dimensional network by forming a series of cross-links that connect polymer chains. This network traps water in its gaps, thereby helping to retain the product's moisture during storage. The baking temperature reduces chain interactions, allowing for the formation of water bonds with the polysaccharide chains. Milinčić *et al.* (2024) reported that the addition of propolis extract to the formulation of oil cake resulted in higher moisture content in the samples containing this additive compared to the control sample. The researchers stated that some compounds in propolis likely contain a large number of hydroxyl groups, which help trap and encapsulate water, thereby enhancing its retention. Consequently, the propolis extract in the cake formulation was effective in retaining moisture during the baking process and afterward.

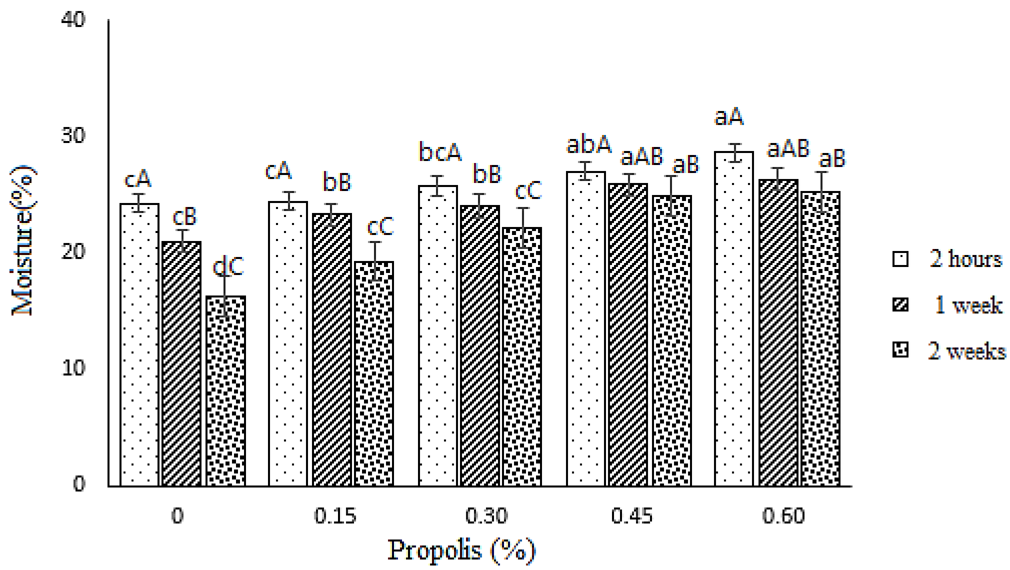

Fig. 3. Effect of different concentrations of ethanolic propolis extract on the moisture content (%) of cupcakes during storage

Different lowercase letters indicate significant differences among treatments at the same storage time, while different uppercase letters indicate significant differences among storage times within the same treatment ($P < 0.05$)

Specific Volume

Cake samples containing 0.15% and 0.30% propolis extract had the highest specific volume compared to the other samples. In contrast, the lowest specific volume was observed in the samples containing 0.45% and 0.60% propolis extract (Fig. 4). These two samples had a lower specific volume than the control sample (the sample without propolis extract). Therefore, adding more than 0.30%

propolis extract not only failed to improve the specific volume of the cake samples but also resulted in a downward trend in specific volume (reduced specific volume compared to the control sample).

The volume of bakery products is influenced by various factors, such as the number of air bubbles entering or leaving the dough (during the mechanical mixing process, air bubbles are incorporated, and during kneading, molding, and dividing, some air bubbles escape), air bubbles produced by biological activity (yeast activity) and chemical activity (such as baking powder and baking soda), their retention in the dough during baking, and proper water evaporation. The presence of additives, such as biopolymers (gums, emulsifiers, proteins, etc.), is also crucial, and if any disturbance occurs in one of these factors, the volume decreases (Scanlon & Koksel, 2024). Based on the results in this section, high levels of propolis extract caused a reduction in the specific volume of the produced samples. The high concentration of this additive in the cake formulation, which was not needed for reinforcing the gluten network or improving the cake texture structure, led to a competition for water absorption between this hydrophilic propolis and the starch in the flour. Since biopolymeric compounds have a higher water absorption capacity than starch, sufficient water was not available for the starch. As a result, starch did not gelatinize properly during baking, leading to a sticky dough with excessive shrinkage and a reduced specific volume of the cake. Additionally, the excessive moisture absorption by the hydrophilic compound negatively impacted volume reduction. By absorbing too much water and preventing the evaporation of some water during the baking process, it hinders the volume expansion related to evaporation, thus reducing the specific volume of the cake. On the other hand, intense water evaporation during the heat transfer process in baking leads to the formation of abnormal holes and pores in the cake. Hydrocolloid compounds, by reducing the heat transfer coefficient and water retention capacity, affect the intensity of water evaporation. Intense evaporation also causes shrinkage and the development of surface roughness and porosity. Excessive evaporation can also lead to the formation of larger holes on the surface of the product. Nasirzadeh Dizaji, Rofehgarinezhad, Tabibiazar, & Alizadeh, (2022) reported that the use of an oleogel containing propolis wax in cake formulation negatively affected the volume and symmetry index of the produced samples compared to the control sample. However, the destructive effects of this compound on the texture properties were not observed in the optimized sample containing 4% propolis wax oleogel (bee propolis). Basturk, Badem, & Ceylan, (2023) also reported that using propolis oleogel in cakes resulted in decreased acceptance of textural properties. Hosseini Khabbazi, Mansouripour, & Saremnezhad, (2023) used propolis extract in toast bread formulation and observed a reduction in the specific volume of the toast bread due to the presence of this additive. However, this reduction was not significant, and considering the positive physicochemical and antimicrobial effects of propolis, the use of this extract up to 2% in toast bread formulations is recommended.

Porosity

Cakes containing 0.15% and 0.30% propolis extract had the highest porosity compared to the control sample. The porosity of sample containing 0.45% propolis and the control sample were statistically similar at a 95% confidence level. The lowest porosity was observed in the sample containing 0.60% propolis extract (Fig. 5). Porosity refers to the number of air-filled cavities within the product, and it is calculated by dividing the total volume of pores by the total volume of the sample. Baking temperature and time affect the porosity of bakery products. As baking begins, the volume and, consequently, the porosity of the product change (Ahmed *et al*., 2024).

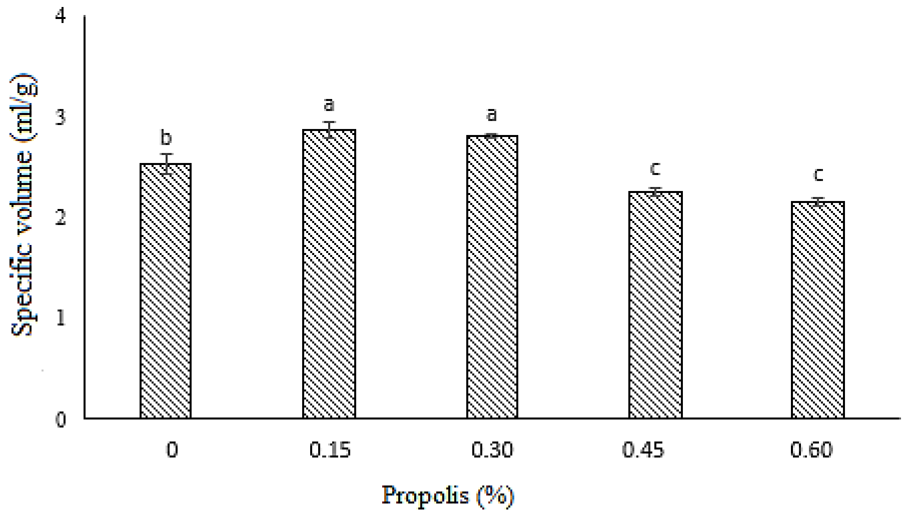

Fig. 4. Effect of different levels of propolis extract on the specific volume of cake
Like letters are not statistically significant at the $P<0.05$ level.

At the beginning of the baking process, the volume of the product increases due to the expansion of gases. During baking, the heat transferred into the product also causes moisture evaporation. The steam produced may become trapped in the cavities within the product's structure, enlarging these pores and increasing porosity. Towards the end of the baking process, significant changes in volume are less noticeable. In the final minutes of baking, due to the formation of a crust and the release of steam, the product may shrink, resulting in a decrease in volume. As the baking temperature increases, volume changes occur more rapidly, which may be due to faster heat transfer into the product and a quicker increase in the temperature of water (Aleman *et al*., 2022). On the other hand, the porosity of the inner texture is influenced by the number of cavities present in the core and how evenly these cavities are distributed. The higher the number of cavities and gas cells and the more uniform their distribution, the higher the porosity of the final product (Scanlon & Koksel, 2024). Tahmouzi *et al*. (2023) stated that if hydrocolloid compounds are used in food formulations at appropriate levels, without disrupting the distribution of air bubbles in the sample, they can help stabilize gas cells by reducing the coalescence of gas cells through the formation of a thick layer on the surface of the cells. As a result, each cell remains separate, and its size is smaller, which significantly impacts increasing porosity. Sahraiyan, Pourhaji, & Alizadeh Behbahani, (2021) used different ingredients as gluten-free dough binders. Their results showed that samples containing hydrocolloids had the highest specific volume and porosity compared to those containing water, cheese powder, oil, etc., because they were more successful in dispersing and maintaining the air bubbles in the dough during both dough preparation and baking. Bozdogan, Ormanli, Kumcuoglu, & Tavman, (2022) explored the combined use of pear pomace powder and xanthan gum in gluten-free cake formulations. The inclusion of xanthan gum was found to increase cake volume and decrease crumb hardness, while pear pomace powder contributed to enhanced water retention. Notably, when used together, pear pomace powder and xanthan gum improved the porosity of the cakes, leading to a softer texture.

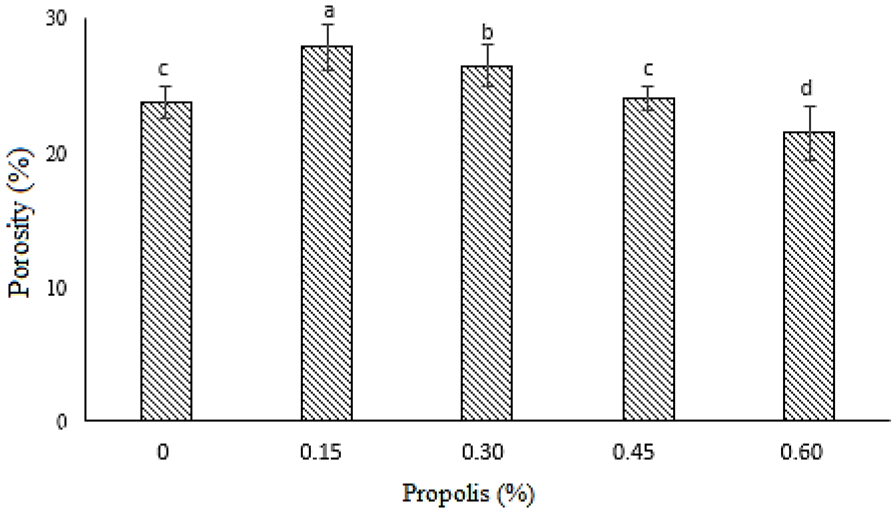

Fig. 5. Effect of different levels of propolis extract on cake porosity
Like letters are not statistically significant at the P<0.05 level.

Texture Firmness

Although specific volume and porosity increased in cakes containing 0.15% and 0.30% propolis extract compared to the control, this trend did not always result in a proportional reduction in firmness. Texture firmness is influenced not only by volume and porosity but also by moisture distribution, starch gelatinization, and interactions between propolis compounds and the gluten–starch matrix. At low propolis concentrations (0.15% and 0.30%), the improvement in volume and porosity contributed to a softer texture shortly after baking. However, propolis is a highly hydrophilic compound, and its interaction with water and gluten proteins may partially limit starch gelatinization. This effect can counterbalance the softening impact of increased porosity, resulting in firmness values that are not strictly inversely correlated with volume. As a result, the increase in firmness observed at certain propolis concentrations does not contradict the higher specific volume and porosity but rather reflects the dominance of water competition and matrix reinforcement effects over structural expansion.

Therefore, the observed firmness behavior at these concentrations reflects the combined effects of structural expansion, moisture retention, and biopolymer interactions rather than being solely dependent on specific volume or porosity. Similar inconsistencies between volume-related parameters and firmness have also been reported in cake systems containing hydrocolloids or phenolic-rich additives, where water competition and matrix reinforcement alter the expected structure–texture relationship.

Samples containing 0.15% and 0.30% propolis extract exhibited lower firmness compared to the control sample within 2 hours after baking. In the same period, samples containing 0.45% and 0.60% propolis extract had the highest firmness among all cake samples. However, after 1 and 2 weeks of storage, all samples had a softer texture than the control. Specifically, the sample with 0.30% propolis extract had the lowest firmness after 1 week, while after 2 weeks, the samples containing 0.30% and 0.45% propolis exhibited the lowest firmness. Over 2-week storage period, the firmness of all cake samples increased, with the control sample showing the most significant increase in firmness compared to the other treatments (Table 3). The firmness of baked products immediately after production is mainly influenced by moisture retention during baking and key technological properties such as specific volume and porosity. Higher moisture retention helps prevent excessive crust hardening, resulting in a softer texture, while increased volume and porosity—associated with a greater number and more uniform distribution of air cells—reduce crumb compactness and contribute to lower firmness. Therefore, samples with higher volume and porosity are generally expected to exhibit softer textures immediately after baking.

Moreover, it was expected that samples with higher moisture retention during storage would maintain a softer texture. This is because the moisture-absorbing components in their formulation help slow down the migration of moisture from the inner texture to the crust. Essentially, the loss of moisture, which is the main cause of staling and firmness decrease in baked goods during storage, occurs at a much slower rate.

If the number of hydrophilic compounds exceeds the formulation's requirements, these additives will absorb more water than starch. This can prevent the complete gelatinization of starch during baking, ultimately accelerating the staling process and increasing the firmness of the stored samples (Sahraiyan *et al.*, 2021). Nasirzadeh Dizaji *et al.* (2022) utilized wax extracted from propolis as a substitute for shortening in cake formulation. Their findings indicated that incorporating oleogel into the cake formulation had a significant impact on the texture and symmetry index of the cake samples. The use of 20% and 40% oleogel containing 4% propolis wax did not have any adverse effects on the texture or overall quality attributes of the cake. Similarly, Hosseinizadeh, Pedram Nia, Saeidi Asl, & Dovlat Abadi, (2020) and Basturk *et al.* (2023) reported that while propolis extract exhibited a positive effect on the texture of oil-based cakes at low concentrations, it led to increased firmness at higher concentrations immediately after baking. Limited studies have investigated the effects of propolis extract on the textural properties of baked products. The majority of research has focused on its application as a natural preservative to extend the shelf life of fruits and vegetables. de Queiroz, Ramos, Armond, Felipini, & Di Piero, (2024) investigated the efficacy of ethanolic extracts of brown and green propolis, along with their homeopathic preparations, against *Colletotrichum scovillei*. The results demonstrated that these propolis extracts possess antifungal properties, effectively inhibiting the pathogen responsible for anthracnose. When incorporated into gelatin-based coatings, propolis not only enhanced the antimicrobial activity but also contributed to the preservation of bell pepper quality during storage.

Table 3- Effect of different levels of propolis extract on the firmness of cake texture over 2 weeks after baking

Treatments	Propolis extract (%)	Tissue stiffness		
		2 hours	1 week	2 weeks
1	0	2.31±0.21 ^{bA}	714±0.19 ^{aB}	15.62±0.22 ^{aC}
2	0.15	2.48±0.17 ^{bA}	4.30±0.06 ^{cB}	8.41±0.47 ^{bC}
3	0.30	2.51±0.04 ^{bA}	3.81±0.02 ^{dB}	5.32±0.63 ^{cC}
4	0.45	2.79±1.11 ^{aA}	4.32±0.10 ^{cB}	5.39±0.27 ^{cC}
5	0.60	2.86±2.09 ^{aA}	4.96±0.14 ^{bB}	7.21±0.06 ^{bC}

Different lowercase letters in each column indicate significant differences among treatments at the same storage time (P<0.05). Different uppercase letters in each row indicate significant differences among storage times within the same treatment (P<0.05).

Crust Color (L*, *a, b*)**

The results indicated that incorporating propolis extract into the cake formulation significantly (P < 0.05) reduced the L* and a* color components. However, when the propolis extract level exceeded 0.30%, the b* color component exhibited an increasing trend. The lowest b* value was observed in the control sample and in the samples containing 0.15% and 0.30% propolis extract, while the highest b* value was recorded in the samples with 0.45% and 0.60% propolis extract (Table 4). The addition of high concentration of propolis extract in the cake formulation resulted in a darker color of the final product. Color changes in food products depend on multiple factors, with baking temperature and time being among the most influential. These changes are primarily attributed to non-enzymatic browning reactions occurring in the food matrix. Consequently, the addition of ingredients that contain substrates affecting these reactions can intensify color changes (Hassan *et al*., 2020). According to Hoseinzadeh & Shirazinejad (2019), crust surface characteristics significantly influence brightness, with smoother surfaces exhibiting better color uniformity compared to wrinkled ones. However, beyond enzymatic and non-enzymatic reactions and the physical nature of the surface (smooth vs. wrinkled), pigments present in additives and the intrinsic color properties of the formulation ingredients can also have a considerable impact on the final product's color. Propolis extract, due to its distinct hue (ranging from light brown to olive green), alters the cake's coloration. The a* color component was found within the negative range (green), whereas baked goods typically exhibit a positive a* value (red spectrum). Nasirzadeh Dizaji *et al*. (2022) reported that the propolis wax in cake formulations led to darkening of the color. The phenolic compounds present in the extracts also contribute to the darkening and opacity of food products, significantly altering both the surface and internal texture color components. Since propolis extract contains significant amounts of phenolic compounds (Refaat, Mady, Sarhan, Rateb, & Alaaeldin, 2021), it is likely that part of the color change in the samples containing this additive, compared to the control, is influenced by polyphenols.

Table 4– Effect of different levels of propolis extract on the amount of color components (L*a*b*) of cake crust

Treatments	Propolis extract (%)	Color components		
		b^*	a^*	L^*
1	0	22.69±0.31 ^{b}	-0.07±0.01 ^{a}	74.53±0.86 ^{a}
2	0.15	23.49±0.25 ^{b}	-0.51±0.03 ^{b}	72.63±0.34 ^{ab}
3	0.30	23.26±0.30 ^{b}	-1.29±0.04 ^{c}	70.46±0.30 ^{abc}
4	0.45	24.76±0.15 ^{a}	-1.36±0.07 ^{c}	68.47±1.21 ^{bc}
5	0.60	25.04±0.03 ^{a}	-1.71±0.08 ^{d}	66.80±2.07 ^{c}

Similar letters in each column are not statistically significant at the P<0.05 level.

Sensory Characteristics of Cake

Form and Shape

The results indicated that samples containing 0.15% and 0.30% propolis extract had superior scores for form and shape compared to the control sample. The form and shape score of 0.15% propolis extract sample was higher than that of 0.30% propolis extract sample, earning the highest score among all the produced samples. Additionally, the findings showed that higher levels of propolis extract (0.45% and 0.60%) had negative effect on the form and shape scores of the samples (Fig. 6)

Surface Characteristics (Crust)

The results indicated that the samples containing 0.15% and 0.30% propolis extract showed similar surface characteristics to the control sample. No significant difference (P<0.05) was observed between these three samples. In contrast, cake samples containing 0.45% and 0.60% propolis extract had the lowest surface characteristic scores compared to the other samples. No significant difference was observed between these two samples at 95% confidence level (Fig. 6).

Lower Surface Characteristics

As a result of the presence of propolis extract and its high concentration in the cake formulation, the lower surface characteristics score of the produced samples significantly decreased (P<0.05). The highest score for lower surface characteristics was observed in the control sample (propolis-free sample), while the lowest score for this parameter was recorded in the two samples containing 0.45% and 0.60% propolis extract (Fig. 6). Samples containing 0.15% and 0.30% propolis extract ranked second in terms of lower surface characteristics scores. All the produced samples, even those with the lowest surface characteristics scores, received an acceptable sensory score from panelists (above 2.5).

Porosity and Pore Structure

The results showed that samples containing 0.15% and 0.30% propolis extract had porosity and pore structure characteristics similar to the control sample (propolis-free sample). No significant difference (P<0.05) was observed between these three samples. In contrast, cake samples containing 0.45% and 0.60% propolis extract exhibited the lowest porosity scores compared to the other samples (Fig. 6).

Texture Firmness and Softness

Sample containing 0.15% propolis extract exhibited superior texture firmness and softness scores compared to the other samples (Fig. 6). The texture firmness and softness score of sample containing 0.30% propolis extract was similar to that of the control sample. No significant difference (P<0.05) was observed between these two samples. Both the control sample and the sample with 0.30% propolis extract ranked second in terms of texture firmness and softness, after the sample containing 0.15% propolis extract. Furthermore, the results indicated that higher levels of propolis extract (0.45% and 0.60%) negatively affected the texture firmness and softness scores of the samples. The lowest texture firmness and softness score was observed in the sample containing 0.60% propolis extract.

Chewability

Sample containing 0.15% propolis extract exhibited superior chewability scores compared to the other produced samples, achieving the highest chewability score. The chewability score of sample containing 0.30% propolis extract was similar to that of the control sample, and no significant difference (P<0.05) was observed between these two samples (Fig. 6). Both the control sample and the sample with 0.30% propolis extract ranked second in terms of chewability, after the sample containing 0.15% propolis extract. Higher levels of propolis extract (0.45% and 0.60%) negatively affected the chewability scores of the samples. The lowest chewability score was observed in the sample containing 0.60% propolis extract. Cake sample containing 0.60% propolis extract was considered unacceptable by the panelists, as it received a chewability score lower than 2.5 in the sensory evaluation.

Smell and Taste

The presence of propolis extract at different concentration from 0.15% to 0.60% in the cake formulation significantly (P<0.05) decreased the smell and taste scores of the samples. The highest smell and taste scores among the cake samples were observed in the control sample, while the lowest score was recorded for the sample containing 0.60% propolis extract. In the sensory evaluation, the smell and taste scores of the cake samples containing 0.15% and 0.30% propolis extract, ranked second and third, respectively, received acceptable scores (greater than 2.5). On the other hand, the samples containing 0.45% and 0.60% propolis extract were deemed unacceptable by the panelists, as they received scores lower than 2.5 (Fig. 6).

To provide an overall comparison of sensory quality, a radar plot (Fig. 6) was used to simultaneously evaluate the main sensory attributes of the control cake and cakes containing 0.15% and 0.30% propolis extract. The radar plot clearly showed that the cake containing 0.15% propolis extract achieved the highest and most balanced sensory scores across most attributes, particularly in form and shape, surface characteristics, texture, and aroma and taste. The 0.30% propolis sample exhibited sensory properties comparable to the control, while higher propolis concentrations were excluded from the radar plot due to their lower sensory acceptance.

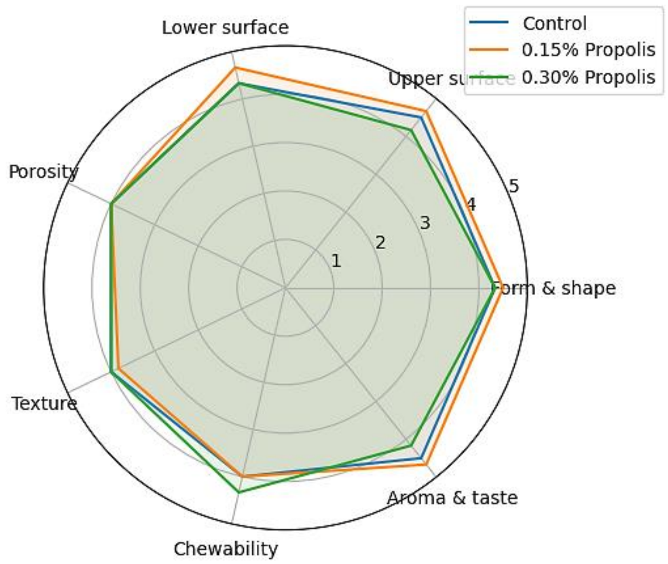

Fig. 6. Radar plot of sensory attributes of cakes containing different levels of propolis extract (control, 0.15%, and 0.30%)

Values represent the mean scores of sensory panelists for form and shape, upper and lower surface characteristics, porosity and crumb structure, texture firmness and softness, chewability, and aroma and taste.

Overall Acceptance

The overall acceptance score is the average of various sensory parameters (shape and form, characteristics of the upper and lower surfaces, porosity and crumb structure, texture firmness and softness, chewability, and smell and taste), calculated after applying the relevant weighting factors.

Sample containing 0.15% propolis extract achieved the highest overall acceptance score compared to the other samples, and this was the only sample with a higher overall acceptance score than the control sample. The overall acceptance scores of samples containing 0.30%, 0.45%, and 0.60% propolis extract were also above 2.5% (Fig. 7). The smell and taste scores of the cakes containing 0.45% and 0.60% propolis extract were below 2.5 and deemed unacceptable. Although these two samples had acceptable overall acceptance scores, they are not recommended.

Cake samples containing 0.15% and 0.30% propolis extract scored higher in terms of shape and form compared to the control sample. The 0.15% propolis extract sample also outperformed the control in terms of texture firmness and softness as well as chewability, while the 0.30% sample showed similar results to the control for these two attributes. Findings also indicated that the upper surface characteristics (crust) and crumb porosity of both propolis-containing samples were comparable to the control. However, all samples received lower scores for lower surface characteristics, aroma, and taste than control. The 0.15% and 0.30% propolis extract samples ranked second and third, respectively, in aroma and taste, following the control sample. Nonetheless, panelists considered the aroma and taste of these two samples acceptable, as their scores exceeded 2.5. There are varying results regarding the effects of propolis on the sensory characteristics of cakes. Nasirzadeh Dizaji *et al*. (2022) reported that incorporating propolis-containing oleogel into cake formulations had no significant impact on the color and texture of the samples and did not affect their overall quality attributes. In contrast, Basturk *et al*. (2023) found that cakes made with propolis oleogel were less acceptable than the control sample. According to their findings, the most negative impact of propolis was on the aroma and taste of the cakes. Similarly, Hosseinizadeh *et al*. (2020) reported comparable results, stating that propolis extract and its increased levels in oil cakes did not negatively affect sensory attributes such as color, texture, and chewability. However, the addition of propolis extract led to a significant decrease in aroma and taste scores.

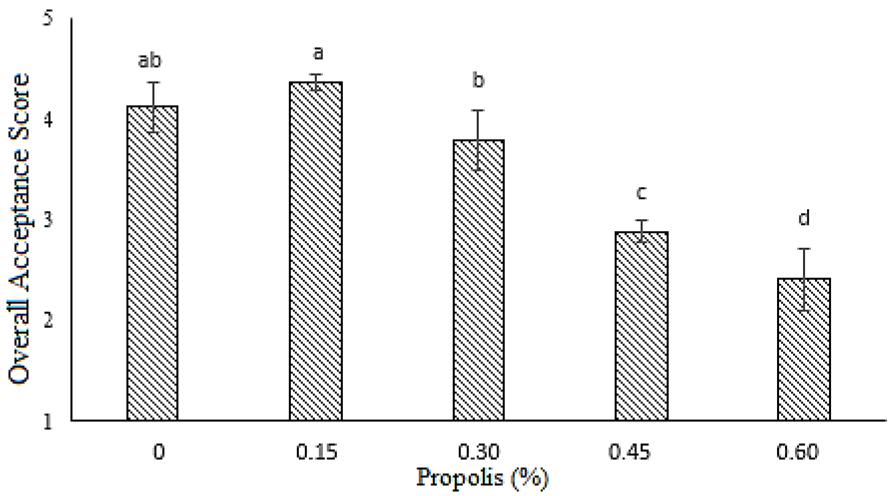

Fig. 7. Effect of different levels of propolis extract on overall cake acceptance score
Like letters are not statistically significant at the P<0.05 level.

Microbial Properties of Propolis-Containing Cake Samples

The results of the study on the antimicrobial effects of propolis in oil cakes showed that after 7 days of storage, all propolis-containing cake samples remained free of mold. From day 14 onward, the mold levels in these samples remained within the acceptable microbial load limits. In contrast, mold growth in the control sample was detected after 7 days, exceeding the permissible standard limits. Additionally, cakes containing 0.45% and 0.6% propolis showed no mold growth even after 12 days of storage (Table 6). These findings indicated that propolis enhances the shelf life of oil cakes due to its antimicrobial properties. Researchers suggest that natural antimicrobial compounds, due to their bioactive components, penetrate the lipid membranes of cells and mitochondria, leading to the leakage of cellular contents and, ultimately, microbial cell death (Bouchelaghem, 2022). Propolis significantly reduced mold growth at a 5% significance level compared to the control sample. Afsharian Torghabeh, Sheikholeslami, & Ataye Salehi, (2016) conducted a study to compare the antimicrobial properties of orange peel essential oil with potassium sorbate, a common chemical preservative, in oil cakes. Their findings revealed that the lowest levels of mold and yeast were observed in samples containing orange essential oil extracted using ultrasound waves at 90% intensity for 5 minutes, as well as in samples containing potassium sorbate. This suggests that orange essential oil can effectively compete with potassium sorbate as a preservative. Similarly, Tajik *et al*. (2017) investigated the effects of green tea and lime essential oils on the physicochemical, microbial, and sensory properties of oil cakes over 28 days of storage.

Their results showed that no mold or yeast growth was detected in samples containing 0.2% and 0.3% lime and green tea essential oils throughout the storage period. Kringel *et al*. (2021) evaluated the antifungal activity of free and encapsulated orange essential oil against Aspergillus spp. The study found that orange essential oil inhibited the growth of all tested Aspergillus species, with minimum inhibitory concentration values ranging from 45.24 to 90.47 mg/mL. Incorporating the essential oil into cakes delayed fungal spoilage from 30 to 150 days, highlighting its effectiveness as a natural antifungal agent in bakery products. Sharayei and Azarpazhooh (2022) optimized the microencapsulation of apple pomace extract and examined its antimicrobial effects in oil cakes. Their findings indicated that the optimal wall composition for microencapsulation included 33.41% maltodextrin (DE 7), 35.384% pectin, and 30.75% maltodextrin (DE 20). The encapsulated apple pomace extracts effectively controlled mold and yeast growth while maintaining the sensory properties of the cake. The lowest mold and yeast growth after 9 days of storage at room temperature was observed in samples containing 4500 mg/L of microencapsulated extract, which was comparable to the effect of 100 mg/L potassium sorbate.

Table 5- Effect of different concentrations of propolis on total mesophilic microorganisms count (Log cfu/g) during 21-day storage

Sample	Production day	7th day	14th day	21st day
Control	0.00^{dA}	3.00^{aB}	4.30^{aC}	4.50^{aD}
0.15%	0.00^{cA}	0.00^{bA}	1.68^{bB}	1.75^{bC}
0.30%	0.00^{cA}	0.00^{bA}	1.30^{cB}	1.48^{cC}
0.45%	0.00^{cA}	0.00^{bA}	1.00^{dB}	1.30^{cC}
0.60%	0.00^{cA}	0.00^{bA}	1.00^{dB}	1.18^{cC}

Different lowercase letters in each column indicate significant differences among treatments at the same storage time ($P < 0.05$). Different uppercase letters in each row indicate significant differences among storage times within the same treatment ($P < 0.05$).

Table 6- Effect of different concentrations of propolis on mold count (Log cfu/g) during 21-day storage

Sample	Production day	7th day	14th day	21st day
Control	0.00^{aA}	2.79^{aB}	4.23^{aC}	4.38^{aD}
0.15%	0.00^{bA}	0.00^{bA}	1.40^{bB}	1.60^{bC}
0.30%	0.00^{bA}	0.00^{bA}	1.00^{cB}	1.17^{cC}
0.45%	0.00^{bA}	0.00^{bA}	0.00^{dA}	0.00^{dA}
0.60%	0.00^{bA}	0.00^{bA}	0.00^{dA}	0.00^{dA}

Different lowercase letters in each column indicate significant differences among treatments at the same storage time ($P < 0.05$). Different uppercase letters in each row indicate significant differences among storage times within the same treatment ($P < 0.05$).

Both total mesophilic microorganisms and mold counts were significantly affected by propolis concentration and storage time ($P < 0.05$). In all samples, microbial counts increased significantly during storage; however, at each storage time, cakes containing propolis showed significantly lower microbial growth compared to the control. The highest inhibitory effect was observed in samples containing 0.45% and 0.60% propolis, in which mold growth was completely inhibited throughout storage. The total mesophilic microorganism count increased in all cake samples over time, reaching its highest level by the end of the third week of storage (Table 5). The highest microbial count was observed in the control sample, which showed a statistically significant difference from other samples ($p < 0.05$). However, on the production day, there was no significant difference in microbial count among the samples ($p > 0.05$). Increasing the amount of propolis in the cake formulation resulted in a lower microbial count. Furthermore, no significant statistical difference ($p > 0.05$) was observed in the total microbial count of propolis-containing samples on days 14 and 21. Research on the antimicrobial activity of medicinal plants and bee-derived products indicates a growing preference for natural preservatives over chemical ones. Propolis, due to its flavonoid content, exhibits antioxidant activity. Its medicinal effects include hepatoprotective and anticancer properties, anti-inflammatory and cytostatic effects, immune system enhancement, and anti-allergenic benefits (Fernández-Calderón *et al*., 2021). Baghbani and Shirazi Nejad (2019) investigated the antioxidant and antimicrobial properties of date seed extract and its effects on the physicochemical, microbial, and sensory properties of cupcakes. All cakes containing different concentrations of date seed extract met standard physicochemical criteria. Sample containing 0.2% date seed extract had the lowest microbial count among the tested samples and received the highest sensory evaluation score. Similarly, Hosseinizadeh and Shirazi Nejad (2019) studied the antioxidant and antimicrobial effects of grape seed extract in sponge cakes. Their results showed that increasing the extract concentration led to a reduction in the total microbial count, confirming the extract's effectiveness in controlling microbial growth and proliferation.

Conclusion

The findings of this study indicate that incorporating propolis extract at levels exceeding 0.30% in cake formulation led to an increase in batter density. Additionally, the presence of this extract at higher concentrations contributed to improved batter consistency. Including propolis extract in the formulation enhanced moisture retention in the cake samples during baking and throughout the storage period (two weeks). However, all cake samples exhibited a reduction in moisture content over time, with the control sample experiencing the highest moisture loss compared to the other formulations. Samples containing 0.15% and 0.30% propolis extract exhibited the highest specific volume and porosity, along with the lowest firmness, within two hours post-baking. Cake formulated with 0.30% propolis extract maintained the lowest firmness after one week, whereas samples containing 0.30% and 0.45% propolis extract exhibited the lowest firmness levels after two weeks of storage. Notably, all cake samples remained softer than the control sample throughout the storage period. Furthermore, the inclusion of propolis extract affected the color of the crust of the cakes. As the concentration of propolis extract increased, the L* and a* color parameters decreased, while the b* parameter increased, resulting in a darker overall appearance of the cake samples. Sensory evaluation results indicated that cakes containing 0.15% and 0.30% propolis extract received comparable or superior scores relative to the control sample in terms of shape, texture firmness and softness, chewability, upper surface characteristics (crust), and porosity. However, the lower surface characteristics, aroma, and taste of these two formulations (0.15% and 0.30%) received slightly lower scores than the control sample, though they remained within the acceptable range according to the sensory panel. Overall, cakes formulated with 0.15% and 0.30% propolis extract were identified as the most promising samples in this study, demonstrating optimal technological and sensory properties. Among the tested formulations, the incorporation of 0.30% ethanolic propolis extract was determined to be the most effective treatment, providing optimal antifungal activity while maintaining desirable physicochemical properties and acceptable sensory characteristics. Therefore, this concentration can be recommended as a natural antifungal preservative for cake formulations.

Author Contributions

Najmeh Adelipour: investigation (equal); software (supporting); writing – original draft (lead). **Masoomeh Mehraban Sang Atash**: Conceptualization (lead); methodology (lead); resources (lead); visualization (equal); writing–review, and editing (equal). **Hanieh Yarabbi**: Formal analysis (equal); methodology (equal); project administration (equal); software (lead); supervision (lead); writing, review, and editing (lead). **Bahareh Sahraiyan**: Formal analysis (equal); methodology (equal); project administration (equal); software (lead); supervision (lead).

Founding Source

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Conflicts of Interest Statement

None declared.

Data Availability Statement

Our research data is available and can be easily accessed. Details of the data and how to request access are available by emailing the corresponding author.

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کاربرد عصاره اتانولی بره‌موم به‌عنوان نگهدارنده طبیعی ضدقارچ: تأثیر بر ویژگی‌های فیزیکوشیمیایی، میکروبی و حسی کیک فنجانی

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چکیده

استفاده گسترده از افزودنی‌های غذایی شیمیایی موجب افزایش نگرانی‌ها در خصوص اثرات نامطلوب احتمالی آن‌ها بر سلامت مصرف‌کنندگان شده است. در این راستا، گرایش روزافزون به سوی ترکیبات ضدمیکروبی طبیعی، زمینه‌ساز معرفی بره‌موم به‌عنوان جایگزینی مناسب برای نگهدارنده‌های سنتتیک گردیده است. هدف از این پژوهش بررسی تأثیر عصاره اتانولی بره‌موم (EPE) به‌عنوان یک عامل ضدقارچ طبیعی بر ویژگی‌های فیزیکوشیمیایی، میکروبی و حسی کیک فنجانی بود. بدین منظور، عصاره اتانولی بره‌موم در سطوح ۰/۱۵، ۰/۳، ۰/۴۵ و ۰/۶ درصد به فرمولاسیون خمیر کیک افزوده شد و خصوصیات کیفی نمونه‌ها مورد ارزیابی قرار گرفت. نتایج نشان داد افزودن EPE در سطوح بالاتر از ۰/۳ درصد موجب افزایش دانسیته و قوام خمیر کیک گردید. همچنین حضور عصاره بره‌موم سبب بهبود نگهداشت رطوبت در طول فرآیند پخت و دوره نگهداری دو هفته‌ای شد، به‌طوری‌که نمونه شاهد بیشترین کاهش رطوبت را نشان داد. کیک‌های حاوی ۰/۱۵ و ۰/۳ درصد EPE بیشترین حجم ویژه و تخلخل و کمترین سفتی (دو ساعت پس از پخت) را در مقایسه با سایر تیمارها دارا بودند. تمامی نمونه‌های حاوی EPE در طول دوره نگهداری بافت نرم‌تری نسبت به شاهد حفظ کردند. از نظر رنگ پوسته، افزایش غلظت EPE موجب کاهش مقادیر L* و a* و افزایش مقدار b* شد که بیانگر تیره‌تر شدن رنگ کیک‌ها بود. ارزیابی حسی نشان داد نمونه‌های حاوی ۰/۱۵ و ۰/۳ درصد عصاره بره‌موم از نظر شکل، بافت، نرمی، جویدگی، ویژگی‌های سطحی و تخلخل تفاوت معنی‌داری با یکدیگر نداشتند و اگرچه امتیاز طعم و عطر آن‌ها اندکی کمتر از نمونه شاهد بود، اما همچنان در محدوده قابل قبول قرار داشت. به‌طور کلی، کاپ‌کیک‌های حاوی ۰/۱۵٪ و ۰/۳۰٪ عصاره پروپولیس الکلی به‌عنوان فرمولاسیون‌های بهینه شناسایی شدند، که در میان آن‌ها، ۰/۳۰٪ EPE بهترین تعادل را بین اثربخشی ضدقارچی، کیفیت فیزیکوشیمیایی و پذیرش حسی ارائه می‌دهد و آن را به یک نگهدارنده طبیعی امیدوارکننده برای محصولات نانوایی تبدیل می‌کند. نتایج حاکی از آن است که عصاره اتانولی بره‌موم پتانسیل بالایی برای استفاده به‌عنوان نگهدارنده طبیعی با خاصیت ضدقارچی در فرمولاسیون کیک دارد.

واژه‌های کلیدی: اثر ضدقارچی، پایداری میکروبی، عصاره بره‌موم، کیک فنجانی، نگهدارنده طبیعی، ویژگی‌های حسی

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