

Development and Characterization of Bee Bread-Fortified Yogurt: A Functional Food Approach

Arı Ekmeği ile Zenginleştirilmiş Yoğurt Geliştirilmesi ve Karakterizasyonu: Fonksiyonel Gıda Yaklaşımı


Candan ERDOGAN¹, Ahmet Sukru DEMIRCI^{2*}, Ozlem NTOUGKIANZI³


Abstract

The use of bee products as a functional ingredient in food systems to enhance product quality attributes has been widely investigated. However, there is a lack of scientific research on the effects of bee bread as an ingredient in yogurt, which is the most widely consumed fermented dairy product in the world. With this in mind, this study was conducted to develop an optimal yogurt formulation incorporating bee bread and to investigate the physical, chemical and health properties of the resulting products. Yoghurt samples were prepared enriched with bee bread extract at concentrations of 0.05%, 0.1% and 0.2%. The yogurt sample enriched with 2% bee bread extract had the highest total solids (13.79%) and ash content (1.79) among the formulations. This formulation also had the highest viscosity value (19.87 mPa.s). The addition of bee bread to yogurt resulted in a food matrix with higher in vitro antioxidant capacity and total phenolic content, while having no negative effect on the sensory and colour properties of the yogurt. The incorporation of 0.2% bee bread extract led to a significant enhancement in total phenolic content, increasing from 120.90 mg GAE kg⁻¹ in the plain yogurt to 252.57 mg GAE kg⁻¹. The highest bee bread level (0.2% w/v) resulted in a DPPH radical inhibition of 32.84%, which was 9.85% and 5.74% higher than those observed in yogurts enriched with 0.05% (22.99%) and 0.1% (27.10%) bee bread extract, respectively, and 18.07% higher than that of the plain yogurt (14.77%). At the same time, highest level of bee bread (0.2%) adversely affected the physical properties of the yogurt, including water-holding capacity and syneresis. Yogurts containing 0.2% and 0.1% bee bread exhibited the greatest L (86.63) and a (-1.14) values, respectively, while all samples showed ΔE values < 2, indicating non-visible colour changes. On the basis of these data, bee bread-based yogurts of 0.05 – 0.1% (w/v) are proposed as a new bio-functional food and perhaps as an alternative option for the improvement of human health.

Keywords: Functional yogurt, Bee products, Physicochemical properties, Antioxidant activity, Sensory analysis

¹Candan Erdogan, Tekirdağ Namık Kemal University, Tekirdağ, Turkey. E-mail: candanerdogan@gmail.com  OrcID: 0009-0000-7695-9267

^{2*}Sorumlu Yazar/Corresponding Author: Ahmet Sukru Demirci, Tekirdağ Namık Kemal University, Faculty of Agriculture, Food Engineering Department, Tekirdağ, Turkey. E-mail: ademirci@nku.edu.tr  OrcID: 0000-0001-5252-8307

³Ozlem Ntougkiantzi, Tekirdağ Namık Kemal University, Tekirdağ, Turkey. E-mail: ontougkiantzi@gmail.com  OrcID: 0009-0001-0787-3619

Atıf: Erdogan, C., Demirci, A. S., Ntougkiantzi, O. (2026). Arı ekmeği ile zenginleştirilmiş yoğurt geliştirilmesi ve karakterizasyonu: fonksiyonel gıda yaklaşımı. *Tekirdağ Ziraat Fakültesi Dergisi*, 23(3): 1108-1117.

Citation: Erdogan, C., Demirci, A. S., Ntougkiantzi, O. (2026). Development and characterization of bee bread-fortified yogurt: a functional food approach. *Journal of Tekirdag Agricultural Faculty*, 23(3): 1108-1117.

©Bu çalışma Tekirdağ Namık Kemal Üniversitesi tarafından Creative Commons Lisansı (<https://creativecommons.org/licenses/by-nc/4.0/>) kapsamında yayımlanmıştır. Tekirdağ 2026

Öz

Arı ürünlerinin, ürün kalitesini artırmak için gıda sistemlerinde fonksiyonel bir bileşen olarak kullanımı yaygın olarak araştırılmıştır. Ancak, dünyada en çok tüketilen fermente süt ürünü olan yoğurta arı ekmeğinin bir bileşen olarak etkilerine ilişkin bilimsel araştırmalar yetersizdir. Bu düşünceden hareketle, bu çalışma, arı ekmeğini içeren en uygun yoğurt formülasyonunu geliştirmek ve elde edilen ürünlerin fiziksel, kimyasal ve sağlıkla ilgili özelliklerini araştırmak amacıyla gerçekleştirilmiştir. Yoğurt örnekleri %0.05, 0.1 ve 0.2 konsantrasyonlarda arı ekmeği özü ile zenginleştirilerek hazırlanmıştır. %2 arı ekmeği ekstraktı ile zenginleştirilmiş yoğurt numunesi, formülasyonlar arasında en yüksek toplam katı madde (13.79%) ve kül içeriğine (1.79) sahipti. Bu formülasyon ayrıca en yüksek viskozite değerine (19.87 mPa.s) sahip olmuştur. Yoğurda arı ekmeği ilavesi, yoğurdun duyuşsal ve renk özellikleri üzerinde olumsuz bir etki oluşturmadan, in vitro antioksidan kapasitesi ve toplam fenolik içeriği daha yüksek bir gıda matrisi oluşturmuştur. %0,2 arı ekmeği ekstraktı ilavesi, toplam fenolik içeriğinde önemli bir artışa yol açarak, sade yoğurttaki 120.90 mg GAE kg⁻¹ değerini 252.57 mg GAE kg⁻¹ değerine çıkarmıştır. En yüksek arı ekmeği seviyesi (%0.2 w/v) %32,84'lük bir DPPH radikal inhibisyonu ile sonuçlanmıştır. Bu değer, %0.05 (22.99%) ve %0.1 (27.10%) arı ekmeği ekstraktı ile zenginleştirilmiş yoğurtlarda gözlemlenenen sırasıyla %9,85 ve %5,74 daha yüksek iken sade yoğurttan (%14.77) ise %18.07 daha yüksektir. Aynı zamanda, en yüksek arı ekmeği seviyesi (%0.2) yoğurdun su tutma kapasitesi ve sinerji dahil olmak üzere fiziksel özelliklerini olumsuz etkilemiştir. %0.2 ve %0.1 arı ekmeği içeren yoğurtlar sırasıyla en yüksek *L* (86.63) ve *a* (-1.14) değerlerini gösterirken, tüm numuneler ΔE değerleri < 2 göstererek gözle görülür renk değişikliği olmadığını ortaya koydu. Bu verilere dayanarak, %0.05 – %0.1 (w/v) arı ekmeği bazlı yoğurtlar yeni bir biyo-fonksiyonel gıda ve belki de alternatif bir gıda olarak önerilmektedir.

Anahtar Kelimeler: Fonksiyonel yoğurt, Arı ürünleri, Fizikokimyasal özellikler, Antioksidan aktivite, Duyusal analiz

1. Introduction

Bee products play an important role in nutrition and in the treatment of diseases, and have been used by humans in various fields since ancient times (Aylanc et al., 2023). A growing number of people today appreciate the therapeutic effect not only of honey, but also of other products with a wide range of applications in apitherapy. Bee products like bee pollen and bee bread are gaining increasing attention in the food industry due to their rich macro- and micronutrient profiles combined with therapeutic properties, aligning with the growing consumer demand for natural and functional foods (Kieliszek et al., 2018). This interest stems from their composition, which includes high levels of macronutrients, essential vitamins (C, K, E), key minerals (K, P, Mg, Ca), bioactive compounds (phenolic acids, flavonoids, phenylamides), and notable health benefits (Dranca et al., 2020, Mayda et al., 2020, Aylanc et al., 2023).

Bee Bread is a distinctive product of great importance to both humans and bees. Its availability is limited, making it considerably more expensive than honey. Consisting mainly of pollen, honey and secretions from the salivary glands of bees, bee bread is a valuable natural resource (Barajas et al., 2012). Bees pack these components into honeycomb cells and seal the mixture with wax and honey (Barene et al., 2015). The stored pollen then undergoes lactic fermentation under anaerobic conditions, facilitated by bacteria and yeasts present in the bee nest environment. This fermented pollen is known as "bee bread" (Fuenmayor et al., 2014). There are some differences between these bee products due to the conversion process of pollen to bee bread under fermentation conditions. Bee bread has a higher nutritional value, improved digestibility, and a more complex chemical composition compared to pollen (Habryka et al., 2016). Its partially fermented components enhance absorption in the human body (Barene et al., 2015). Rich in peptides and free amino acids, bee bread serves as an excellent dietary supplement, helping to compensate for vitamin and nutrient deficiencies. Bee bread also possesses beneficial properties that aid in the removal of various toxins from the body (Habryka et al., 2016). The nutritional potential of bee bread extends beyond its direct consumption, and previous studies have mainly focused on its physicochemical characteristics (Dranca et al., 2020; Tomas et al., 2017) as well as its antioxidant (Mayda et al., 2020) and antimicrobial activities. However, the number of studies using this bee product as an ingredient in foods (Mohammad et al., 2021) is very limited compared to pollen.

Yogurt is an easily digestible and tasty food with high nutritional value and therapeutic properties, providing important nutrients. Yogurt is also the most widely consumed fermented dairy product in the world. Although it contains high nutritional value, it cannot be considered as an important source of polyphenols, antioxidants and protein (Azam et al., 2021). In recent years, many studies have focused on improving the quality of yogurt, including sensory quality, shelf life and functional properties (Basiri et al., 2022, Zahid et al., 2022). Although some processing techniques, such as the addition of synthetic chemicals, are available and used, there are concerns about their potential toxicity to the human body and negative impact on the nutritional value of yogurt. Therefore, efforts are being made to find new and safe additives from natural sources.

Yogurt can potentially be fortified with bee bread to increase the quantity of beneficial bioactives and enhance its textural, microbiological, synergetic, and sensory qualities, among other benefits. Based on the above information, this study aimed to evaluate the physicochemical, functional, and sensory properties of homemade yogurt fortified with bee bread extract. There are no studies in which bee bread was added to yogurt, although there is one study in the literature on enriching yogurt with bee pollen (Karabagias et al. 2018).

2. Materials and Methods

2.1. Materials

Pasteurized cow's milk (containing 3.0% protein, 3.5% fat, 4.5% carbohydrate, and with a pH of 6.96) was sourced from Süttaş (Turkey). A commercial freeze-dried yogurt starter culture, comprising *Lactobacillus delbrueckii* subsp. *bulgaricus* (*L. bulgaricus*) and *Streptococcus thermophilus* (*S. thermophilus*), was supplied by Peyma-Chr. Hansen A/S, (İstanbul, Turkey).

2.2. Bee bread extract

Bee bread was collected over from beehives located in the north-western regions of Turkey in 2024. Bee bread extract (BBE) was prepared through extraction utilizing 70% ethanol as the solvent. For each 20 g of fresh bee

bread, 200 g of 70% ethanol was added, and the mixture was subjected to extraction using a Soxhlet apparatus for 2 hours under boiling conditions. The resulting solution was filtered, and the filtrate was subsequently concentrated using a rotary evaporator. Final evaporation was carried out in a water bath at 50 °C until complete solvent removal, as indicated by the attainment of a constant weight. The bee bread extracts were stored at 4 °C until further use.

2.3. Preparation of yogurt samples

Branded and pasteurised milk was used to make a yogurt that was similar to home-made yogurt, without the use of any additional milk powder. Pasteurised milk was heat-treated in a water bath at 85 °C for 10 minutes. It was then rapidly cooled and chilled at 43 °C. A culture mixture containing *S. thermophilus* and *L. delbrueckii bulgaricus* in a 1:1 ratio was used as the starter culture for yogurt production. The yogurt culture was inoculated into milk (2.5 ml kg⁻¹ milk) after activation in one litre of sterilised skimmed milk at 30 °C for 30 minutes. The inoculated milk was then divided into 4 groups and bee bread extract was added at different concentrations (0% (control), 0.05%, 0.1% and 0.2%). The milk was then transferred to 100 g plastic containers and incubated at 42 °C until the pH dropped to 4.6. All samples were stored at 4 ± 1 °C for further analysis (Demirci and Gurbuz, 2023).

2.4. Physicochemical analysis

The pH of the yogurt samples was measured using a calibrated pH meter (Interlab, Turkey) as described by Eser and İnanç (2022). Titratable acidity and total solids were determined following the method of do Espírito Santo et al. (2012). Ash content was analyzed by incineration in a muffle furnace at 600 °C for at least 4 h until the absence of black ash, in accordance with AOAC (2000) method 923.03. Syneresis was assessed by placing 5 g of each sample on Whatman No. 43 filter paper and allowing it to drain into a glass container for 120 min at 4 °C (Gurbuz and Demirci, 2023). The amount of separated whey was expressed as a percentage of the initial yogurt weight and calculated using Eq. (1).

$$\text{Syneresis (\%)} = \frac{\text{Total weight of separated liquid}}{\text{Total weight of the yoghurt sample}} \times 100 \quad (\text{Eq 1.})$$

A 10 g sample was centrifuged at 5000 × g for 10 min at 4 °C to evaluate the water holding capacity (WHC), as described by Gurbuz and Demirci (2023). The resulting precipitate, obtained after removing the supernatant, was weighed. WHC was then calculated using the following formula:

$$\text{WHC} = \frac{\text{initial yoghurt weight} - \text{supernatant}}{\text{original yoghurt weight}} \times 100 \quad (\text{Eq 2.})$$

2.5. Determination of total phenolic content (TPC)

The TPC of the samples was determined by a spectrophotometric method using the Folin–Ciocalteu reagent, following a modified protocol described by Wolfe et al. (2003). Briefly, 0.5 mL of sample was mixed with 2.5 mL of 10% Folin–Ciocalteu reagent and 2.0 mL of 75% (w/v) Na₂CO₃. The mixture was vortexed for 15 s and incubated at room temperature for 90 min to allow color development. Absorbance was measured at 720 nm using a UV–visible spectrophotometer. TPC was expressed as mg kg⁻¹ gallic acid equivalents (GAE), calculated from a gallic acid calibration curve.

2.6. Determination of 2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity

DPPH solution was determined according to the modified method of Brand-Williams et al. (1995). DPPH was prepared at a concentration of 100 μM in methanol. Freshly prepared 100 μl of the extract was mixed with 900 μl HCl (pH 7.4) and 2 ml DPPH solution, and the mixture was kept at room temperature for 35 min. As a control, 80% methanol was used instead of the sample and the absorbances were measured after 35 min by zeroing with methanol at 517 nm in the spectrophotometer.

2.7. Color characteristics

The color characteristics of the yogurt samples were determined using a colorimeter (Chroma Meter CR-400, Konica Minolta, Japan), which provided L* (lightness), a* (red–green), and b* (yellow–blue) values. The instrument was calibrated using a white standard plate six times prior to taking the measurements. The total color difference (ΔE*) between the control and samples was calculated using the following formula (Goswami et al., 2015):

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (\text{Eq 3.})$$

2.8. Viscosity measurements

The viscosity of the samples was determined using a vibro viscometer (SV-10; A & D Co., Ltd., Tokyo, Japan). This viscometer operates by controlling the vibration amplitude of sensor plates immersed in the sample and calculating viscosity based on the electric current required to maintain this vibration.

2.9. Sensory evaluation

The twenty panelists evaluated the appearance, taste, odor, color, flavor, texture and overall acceptability of yogurt samples. For each parameter, a nine-point hedonic scale was used, with 1 being extremely disliked and 9 being extremely liked

2.10. Data analysis

All of the data were obtained in triplicate ($n = 3$) and the results were expressed as means \pm standard deviations. Statistical analyses were carried out using JMP© 7.0 software (SAS Institute, Inc.). Differences among samples throughout the storage period were evaluated by two-way analysis of variance (ANOVA). When significant effects were detected, mean comparisons were performed using Tukey's multiple comparison test at the 5% significance level.

3. Results and Discussion

3.1. Physicochemical characteristics of yogurt samples

The physicochemical characteristics of the yogurt formulations are shown in *Table 1*. The physicochemical characteristics of yogurts fortified with BBE were significantly affected in comparison to the control, as presented in *Table 1*. As expected, plain yogurt had the lowest total solids in this study due to the lack of added ingredients. Yogurts fortified with 2% BBE exhibited significantly higher total solids (13.79%) than the other formulations, whereas no statistically significant differences were observed between the 0.05% and 0.1% BBE-fortified yogurts ($p > 0.05$). Consistently, the 0.2% BBE-fortified yogurt showed the highest ash content, whereas the inclusion of 0.05% BBE did not significantly influence this parameter. Comparable results on total solids were reported by Gurbuz and Demirci (2023), while Öztürk et al. (2018) presented similar findings on ash content in fortified yogurts.

The addition of BBE to yogurt slightly decreased the pH and increased the acidity compared to the control sample. However, there was no difference ($p > 0.05$) between samples with 0.1% and 0.2% supplementation. Gunes Bayır et al. (2020) reported that propolis had an acidity increasing effect in probiotic yogurt ($p < 0.05$) and there was no significant change in pH values. Similarly, Korkmaz et al. (2021) found that the addition of propolis did not affect the pH of yogurt. On the contrary, as observed in other previous studies (Güney and Yılmaz, 2013, El-Deeb, 2017), propolis supplementation increased the pH and reduced the acidic taste of yogurt and other dairy products.

Water holding capacity (WHC) is a desirable property of yogurt gel, as it reflects the coagulation stability of yogurt and is strongly influenced by milk composition and acidity (Srisuvor et al., 2013). The sample containing 0.05% BBE and the control had the highest WHC values (45.50 and 43.10%) with no significant difference between them. In the meantime, the WHC value decreased with a further increase in the proportion of BBE added to the yogurt. Similarly, Korkmaz et al. (2021) showed that propolis had a significant reducing effect on WHC in yogurt.

In contrast to WHC, syneresis is an undesirable physical property, a major visible defect that appears as an accumulation of whey on the surface of yogurt gels and can have an adverse effect on the consumer acceptability of the product (Purwandari et al., 2007). All yogurt samples showed varying degrees of syneresis (*Table 1*), with high BBE fortified yogurt (0.1% and 0.2%) displaying more whey separation than the non-fortified plain yogurt, possibly due to an imbalance in osmotic potential caused by depletion flocculation of casein micelles in the presence of non-adsorbing polymers such as dietary fibre from BBE (Repin et al., 2012). Furthermore, the decrease in pH from 4.21 to 3.74-3.76 with the addition of BBE probably resulted in shrinkage of the casein network and

consequently more whey excretion due to a decrease in the net negative charge of casein micelles, leading to a decrease in electrostatic repulsion between charged molecules and an increase in casein-casein attractions due to enhanced hydrophobic interactions (Lee and Lucey, 2010).

Viscosity reflects the firmness and consistency of yogurt, with higher levels serving as an indicator of better yogurt quality (Hasani et al., 2016). The viscosities of certain samples differed significantly from each other, ranging from 10.09 to 19.87 mPa.s. The apparent viscosities of the samples with 0.05 and 0.1% BBE were lower than those of plain yogurt, whereas the viscosity value of the sample with 0.2% BBE was the highest. The effect of the added product on the viscosity of yogurt has been observed to vary in other enrichment studies (Srisuvor et al., 2013, Mousavi et al., 2019, Demirci et al., 2020).

3.2. Radical scavenging activity and total phenolic contents

The influence of bee bread extracts on DPPH radical scavenging activity and total phenolic content is presented in *Table 1*. The total phenolic content of the yogurts enriched with bee bread was significantly influenced ($p < 0.05$) by the concentration of the incorporated BBE. It is worth noting that a gradual increase in BBE levels led to a consistent rise in phenolic content, ranging from 120.90 mg GAE kg⁻¹ in the control sample to 252.57 mg GAE kg⁻¹ in the sample containing 0.2% BBE. These findings align with those of Mohammed et al. (2021), who reported a significant increase ($p < 0.05$) in total phenolic content in fish sausages with higher concentrations of bee bread extract added to the samples.

As shown in *Table 1*, the antioxidant activity assessed by the DPPH method increased significantly ($p < 0.05$) with the addition of bee bread extracts across all yogurt formulations. The highest level of bee bread (0.2% w/v) resulted in a 32.84% inhibition of DPPH radicals. In comparison, yogurts enriched with 0.05% and 0.1% BBE exhibited 22.99% and 27.10% inhibition, respectively, while the plain yogurt showed a lower inhibition value of 14.77%. The antioxidant activity of bee bread yogurts was partly due to the presence of phenolic compounds such as phenolic acids, flavonoids and phenylamides found in bee bread (Aylanc et al., 2021). Supplementation with bee bread or bee pollen has also been reported to increase DPPH radical scavenging activity in various products, including yogurt milk (Karabagias et al., 2018), fish sausage (Mohammed et al., 2021), biscuits (Krystyan et al., 2015) and gluten-free bread (Conte et al., 2020). Consistent with the findings of this study, the antioxidant activities of these products were positively correlated with the amounts of bee products incorporated.

3.3. Color measurements

Table 1 presents the impact of bee bread extracts on the color parameters of the yogurt samples. The highest L

Table 1. Proximate composition, antioxidative activity, viscosity and color parameters of yogurts fortified with different percentage of BBE

Physicochemical characteristics	Control	BBE		
		0.05%	0.1%	0.2%
Total solids (%)	12.59±0.01 ^c	12.93±0.13 ^b	13.01±0.19 ^b	13.79±0.17 ^a
pH	4.21±0.005 ^a	3.80±0.015 ^b	3.76±0.005 ^c	3.74±0.015 ^c
Titrateable acidity (%)	0.88±0.08 ^b	0.89±0.01 ^{ab}	0.91±0.01 ^a	0.91±0.01 ^a
Water holding capacity (%)	43.10±0.30 ^a	45.50±2.90 ^a	40.35±2.65 ^b	37.50±1.10 ^c
Syneresis (% v/w)	3.97±0.06 ^c	3.54±0.04 ^d	4.71±0.04 ^b	5.29±0.06 ^a
Ash content	1.36±0.89 ^c	1.39±0.03 ^c	1.57±0.02 ^b	1.79±1.63 ^a
Viscosity (mPa.s)	16.83±2.08 ^{ab}	10.09±0.94 ^c	14.50±0.78 ^{bc}	19.87±2.70 ^a
Total phenolic content (mg GAE kg ⁻¹)	120.90±0.35 ^d	153.66±1.68 ^c	199.86±6.5 ^b	252.57±10.05 ^a
DPPH inhibition (%)	14.77±2.86 ^d	22.99±2.58 ^c	27.10±2.06 ^b	32.84±0.17 ^a
L*	86.45±0.025 ^b	86.25±0.03 ^c	86.49±0.01 ^b	86.63±0.03 ^a
a*	-1.22±0.00 ^b	-1.28±0.00 ^d	-1.14±0.01 ^a	-1.26±0.01 ^c
b*	6.29±0.01 ^c	6.37±0.02 ^c	6.75±0.03 ^a	6.60±0.06 ^b
ΔE	—	0.22	0.47	0.36

BBE: Bee bread extract. Values are expressed as mean ± standard deviation (n = 3). Values in same row having different superscripts differ significantly ($p < 0.05$). L* ranging from 0 (black) to 100 (white), a* ranging from red (+a*) to green (-a*), b* ranging from yellow (+b*) to blue (-b*).

and a values were observed in yogurts supplemented with 0.2% (86.63) and 0.1% (-1.14) BBE, respectively. The b value was similar ($p>0.05$) between the control and the sample containing 0.05% BBE; however, these values were lower compared to those of the samples enriched with 0.1% and 0.2%. The total color difference (ΔE) is also given and samples had ΔE values < 2 , indicating non-visible color changes (Lee and Coates, 2003). These results reflect differences that are barely visible to the human eye, indicating that the inclusion of BBE has maintained pigment stability in this formulation.

3.4. Sensorial properties

The sensory assessment is shown in *Figure 1*. According to the data, the addition of bee bread at concentrations ranging from 0.05% to 0.1% had no effect on any of the sensory attributes of the yogurt. Therefore, the yogurts containing bee bread exhibited acceptability levels comparable to those of plain yogurt. However, although the 0.2% sample received lower sensory scores compared to the others, this difference was not statistically significant except for texture. The lower texture scores for the 0.2% BBE-samples seemed to be related to the higher syneresis and lower WHC values when compared with the other fortified samples and plain yogurt. In an earlier study conducted by Silvino et al. (2015), the addition of propolis (at concentrations ranging from 0.01% to 0.4%) to yogurt had no effect on any of its sensory attributes. However, some adverse effects were observed when yogurt (Karabagias et al., 2018, Korkmaz et al., 2021), gluten-free bread (Conte et al., 2018) and milk (El-Deeb, 2017) were supplemented with the highest levels of bee products (e.g. pollen, propolis). This observation is in line with the results of the current study.

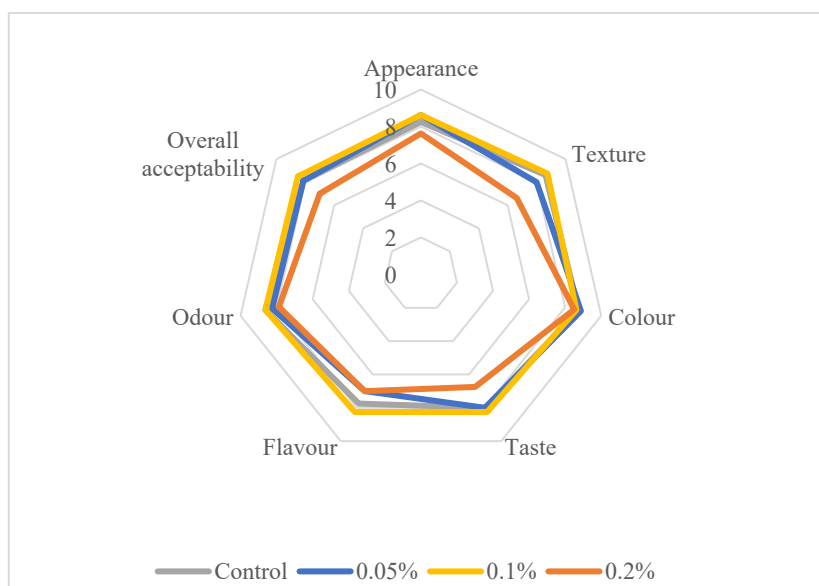


Figure 1. Sensorial attributes of yogurts fortified with different percentage of BBE

4. Conclusions

This study aimed to assess the physicochemical, functional, and sensory properties of yogurt enriched with bee bread extract (BBE), a natural ingredient abundant in nutrients and health-promoting compounds. The incorporation of bee bread into yogurt may promote healthier eating habits among consumers worldwide, as it significantly enhances in vitro antioxidant capacity and total polyphenol content compared to plain yogurt. In addition, the supplementation of bee bread did not significantly affect the sensory properties of the yogurt such as appearance, taste, odor, color, flavor and overall acceptability. The addition of BBE also did not cause visible color differences in the products. However, the highest concentration used in this study (0.2%) has a negative effect on the physical properties of yogurt, such as WHC and syneresis, and on sensory properties such as texture. On the basis of these data, bee bread-based yogurts of 0.05 – 0.1% (w/v) are proposed as a new bio-functional food and perhaps as an alternative option for the improvement of human health.

Acknowledgment

This research was supported with a Grant (2209-A - Research Project Support Programme for Undergraduate Students) from The Scientific and Technological Research Council of Turkey (TUBITAK).

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Demirci, A.S.; Design: Demirci, A.S.; Erdogan, C.; Data Collection or Processing: Demirci, A.S., Erdogan, C., Ntougkiantzi, O.; Statistical Analyses: Demirci, A.S., Ntougkiantzi, O.; Literature Search: Demirci, A.S.; Erdogan, C.; Writing, Review and Editing: Demirci, A.S.

References

- Association of Official Analytical Chemists (AOAC). (2000). Official Methods of Analysis of AOAC International (17th ed.). Helrich, K. (Ed.). Washington, D. C., U. S. A.
- Aylanc, V., Falcao, S. I. and Vilas-Boas, M. (2021). From the hive to the table: Nutritional value, digestibility and bioavailability of dietary phytochemicals present in bee pollen and bee bread. *Trends in Food Science & Technology*, 109: 464–481.
- Aylanc, V., Falcao, S. I. and Vilas-Boas, M. (2023). Bee pollen and bee bread nutritional potential: Chemical composition and macronutrient digestibility under in vitro gastrointestinal system. *Food Chemistry*, 413: 135597.
- Azam, M. S., Ahmed, S., Islam, M. N., Maitra, P., Islam, M. M. and Yu, D. (2021). Critical assessment of mycotoxins in beverages and their control measures. *Toxins*, 13(5): 323.
- Barajas, J., Cortes-Rodriguez, M. and Rodríguez-Sandoval, E. (2012). Effect of temperature on the drying process of bee pollen from two zones of Colombia. *Journal of Food Process Engineering*, 35(1): 134–148.
- Barene, I., Daberte, I. and Siksnas, S. (2015). Investigation of bee bread and development of its dosage forms. *Medicinos Teorija ir Praktika*, 21(1): 16–22.
- Basiri, S., Tajbakhsh, S. and Shekarforoush, S. S. (2022). Fortification of stirred yogurt with mucilage-free flaxseed and its physicochemical, microbial, textural and sensory properties. *International Dairy Journal*, 131: 105384.
- Brand-Williams, W., Cuvelier, M. E. and Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. *Lebensmittel-Wissenschaft und Technologie*, 28: 25–30.
- Conte, P., Del Caro, A., Urgeghe, P. P., Piga, A., Fadda, C. and Pinna, M. (2020). Nutritional and aroma improvement of gluten-free bread: Is bee pollen effective? *LWT – Food Science and Technology*, 118: 108861.
- Demirci, A. S. and Gurbuz, B. (2023). Fortification of yoghurt with xanthan gum biosynthesized from grape juice pomace: Physicochemical, textural and sensory characterization. *Journal of Tekirdag Agricultural Faculty*, (20) 2: 452–460.
- Demirci, T., Sert, D., Aktaş, K., Atik, D. S., Öztürk Neğiş, H. İ. and Akin, N. (2020). Influence of hot and cold break tomato powders on survival of probiotic *Lactobacillus paracasei* subsp. *paracasei* F19, texture profile and antioxidative activity in set-type yogurts. *LWT – Food Science and Technology*, 118: 108855.
- Dranca, F., Ursachi, F. and Oroian, M. (2020). Bee bread: Physicochemical characterization and phenolic content extraction optimization. *Foods*, 9(10): 1358.
- El-Deeb, A. M. (2017). Utilization of propolis extract as a natural preservative in raw milk. *Journal of Food and Dairy Sciences*, 8: 315–321.
- Eser, İ. H. and İnanç, A. L. (2022). Production of Anatolian water buffalo butter using different methods. *Journal of Tekirdag Agricultural Faculty*, 19(1): 215–226.
- Espírito Santo, A. P., Perego, P., Converti, A. and Oliveira, M. N. (2012). Influence of milk type and addition of passion fruit peel powder on fermentation kinetics, texture profile and bacterial viability in probiotic yogurts. *LWT – Food Science and Technology*, 47(2): 393–399.
- Fuenmayor, B., Zuluaga, D., Díaz, M., Quicazán, M. C., Cosio, M. and Celis, M. E. (2014). Evaluation of the physicochemical and functional properties of Colombian bee pollen. *Revista MVZ Córdoba*, 19(1): 4003–4014.
- Goswami, D., Gupta, R. K., Mridula, D., Sharma, M. and Tyagi, S. K. (2015). Barnyard millet-based muffins: Physical, textural and sensory properties. *LWT – Food Science and Technology*, 64(1): 374–380.
- Gunes-Bayır, A., Bilgin, M. G., Kutlu, S. S., Demirci, D. and Gölgeci, F. N. (2020). Microbiological, chemical and sensory analyses of probiotic yogurts supplemented with clove and propolis. *Journal of Food Science and Nutrition Research*, 3(2): 112–120.
- Güney, F. and Yılmaz, M. (2013). Antibacterial, antiviral, antitumour, antifungal and antioxidant activity of propolis with its chemical content. *Bee Studies*, 10: 25–28.
- Gurbuz, B. and Demirci, A. S. (2023). Probiotic yogurt fortified with rosehip seed powder: Viability, physicochemical and sensorial properties. *International Food Research Journal*, 30(5): 1187–1200.
- Habryka, C., Kruczek, M. and Drygas, B. (2016). Bee products used in apitherapy. *World Scientific News*, 48: 254–258.
- Hasani, S., Khodadadi, I. and Heshmati, A. (2016). Viability of *Lactobacillus acidophilus* in rice bran-enriched stirred yogurt and physicochemical and sensory characteristics during refrigerated storage. *International Journal of Food Science and Technology*, 51(11): 2485–2492.
- Karabagias, I. K., Karabagias, V. K., Gatzias, I. and Riganakos, K. A. (2018). Bio-functional properties of bee pollen: The case of bee pollen yogurt. *Coatings*, 8(12): 423.
- Kieliszek, M., Piwowarek, K., Kot, A. M., Błażejczak, S., Chlebowska-Śmigiel, A. and Wolska, I. (2018). Pollen and bee bread as new health-oriented products: A review. *Trends in Food Science & Technology*, 71: 170–180.
- Korkmaz, I. O., Bilici, C. and Korkmaz, S. (2021). Sensory, pH, syneresis, water-holding capacity and microbiological changes in homemade yogurt prepared with maca powder and propolis extract. *International Journal of Gastronomy and Food Science*, 23: 100291.

- Krystyan, M., Gumul, D., Ziobro, R. and Korus, A. (2015). The fortification of biscuits with bee pollen and its effect on physicochemical and antioxidant properties in biscuits. *LWT – Food Science and Technology*, 63: 640–646.
- Lee, H. S. and Coates, G. A. (2003). Effect of thermal pasteurization on Valencia orange juice color and pigments. *Lebensmittel-Wissenschaft + Technologie*, 36(1): 153–156.
- Lee, W. J. and Lucey, J. A. (2010). Formation and physical properties of yogurt. *Asian-Australasian Journal of Animal Sciences*, 23(9): 1127–1136.
- Mayda, N., Ozkok, A., Bayram, N. E., Gerçek, Y. C. and Sorkun, K. (2020). Bee bread and bee pollen of different plant sources: Determination of phenolic content, antioxidant activity, fatty acid and element profiles. *Journal of Food Measurement and Characterization*, 14: 1795–1809.
- Mohammed, S. M., Badrul Hisham, A. A., Mustapa, N. A., Chan, K. W. and Zawawi, N. (2021). Proximate analysis, antioxidant activity and antibacterial activity of fish sausages fortified with bee bread extract. *Journal of Food Quality*, 2021: 1–9.
- Mousavi, M., Heshmati, A., Garmakhany, A. D., Vahidinia, A. and Taheri, M. (2019). Optimization of the viability of *Lactobacillus acidophilus* and physicochemical, textural and sensorial characteristics of flaxseed-enriched stirred probiotic yogurt by response surface methodology. *LWT – Food Science and Technology*, 102: 80–88.
- Öztürk, H. İ., Aydın, S., Sözeri, D., Demirci, T., Sert, D. and Akın, N. (2018). Fortification of set-type yogurts with *Elaeagnus angustifolia* L. flours: Effects on physicochemical, textural and microstructural characteristics. *LWT – Food Science and Technology*, 90: 620–626.
- Purwandari, U., Shah, N. P. and Vasiljevic, T. (2007). Effects of exopolysaccharide-producing strains of *Streptococcus thermophilus* on technological and rheological properties of set-type yogurt. *International Dairy Journal*, 17(11): 1344–1352.
- Repin, N., Scanlon, M. G. and Fulcher, R. G. (2012). Phase behaviour of casein micelles and barley beta-glucan polymer molecules in dietary fibre-enriched dairy systems. *Journal of Colloid and Interface Science*, 377(1): 7–12.
- Silvino, J. N. O., Lima, V. V. C., de Melo Alves, M. A., dos Santos Silva, A., Santos, A. F. O., Macedo, R. O., Escodro, P. B., Junior, I. D. B., Delgado Silvano, M. C. and Nascimento, T. G. (2015). Characterization of Yogurts Fortified with Red Propolis Extract and Whey Powder. 11th Latin American Symposium of Food Science. Campinas, Brazil.
- Srisuvor, N., Chinprahast, N., Prakitchaiwattana, C. and Subhimaros, S. (2013). Effects of inulin and polydextrose on physicochemical and sensory properties of low-fat set yogurt with probiotic-cultured banana purée. *LWT – Food Science and Technology*, 51(1): 30–36.
- Tomas, A., Falcao, S. I., Russo-Almeida, P. and Vilas-Boas, M. (2017). Potentialities of bee bread as a food supplement and source of nutraceuticals: Botanical origin, nutritional composition and antioxidant activity. *Journal of Apicultural Research*, 56: 219–230.
- Wolfe, K., Wu, X. and Liu, R. H. (2003). Antioxidant activity of apple peels. *Journal of Agricultural and Food Chemistry*, 51: 609–614.
- Zahid, H. F., Ranadheera, C. S., Fang, Z. and Ajlouni, S. (2022). Functional and healthy yogurts fortified with probiotics and fruit peel powders. *Fermentation*, 8(9): 469.