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Effects of *Berberis vulgaris* L. Extract on the Physicochemical, Sensory, and Textural Properties of Raw and Cooked Patties

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Abstract: The effects of adding different concentrations (0.1%, 0.2%, and 0.4%) of *Berberis vulgaris* fruit extract to raw beef patties on their physicochemical properties were investigated. Physicochemical, sensory, and textural analyses were also performed on cooked beef patties. The addition of the extract did not cause a significant change in the approximate composition of the patties. (P<0.01). Initially, it significantly affected the TBARS value in all groups (P<0.05). However, there was no significant difference in TBARS values after cooking (p>0.05). While no significant difference was observed in the color values before cooking, cooking reduced L*, *a**, and b* values. The cooking yield significantly affected all groups (P<0.01) and was reduced by adding Berberis extract. The incorporation of the extract did not induce any statistically important alterations in the sensory attributes of the patties. Furthermore, texture analysis revealed highly significant effects on the hardness, gumminess, and chewiness values across all groups (P<0.01). The results demonstrate that the extract did not notably change the patties' physicochemical properties. However, it effectively reduced lipid oxidation and enhanced their textural qualities. This study supports the potential use of *B. vulgaris* extract as a natural additive to improve the quality of beef patties.

Berberis vulgaris L. Ekstraktının Çiğ ve Pişmiş Köftelerin Fizikokimyasal, Duyusal ve Tekstürel Özelliklerine Etkisi

Anahtar Kelimeler
Berberis vulgaris L.,
Köfte,
TBARS,
Tekstür

Öz: Farklı konsantrasyonlarda (%0,1, %0,2 ve %0,4) *Berberis vulgaris* meyve ekstraktı eklenmesinin çiğ sığır köftelerinin fizikokimyasal özellikleri üzerindeki etkileri araştırılmıştır. Ayrıca, pişmiş sığır köfteleri üzerinde fizikokimyasal, duyusal ve tekstürel analizler yapılmıştır. Ekstraktın ilavesi, köftelerin yaklaşık bileşiminde önemli bir değişikliğe neden olmamıştır. pH değerlerindeki değişim, tüm gruplarda anlamlı şekilde etkilenmiştir (P<0.01). İlk başta, TBARS değerini tüm gruplarda önemli ölçüde etkilemiştir (P<0.05). Ancak, pişirme sonrasında TBARS değerlerinde önemli bir fark gözlenmemiştir (p>0.05). Pişirmeden önce renk değerlerinde anlamlı bir fark gözlenmezken, pişirme L*, a* ve b* değerlerini azaltmıştır. Pişirme verimi, tüm grupları önemli ölçüde etkilemiştir (P<0.01). Köftelere Berberis ekstraktı eklenmesi pişirme verimini azaltmıştır. Ekstraktın ilavesi, köftelerin duyusal özelliklerinde istatistiksel olarak anlamlı bir değişiklik oluşturmamıştır. Ayrıca, tekstür analizi, tüm gruplarda sertlik, yapışkanlık ve çiğnenebilirlik değerleri üzerinde yüksek derecede anlamlı etkiler ortaya koymuştur (P<0.01). Sonuçlar, ekstraktın köftelerin fizikokimyasal özelliklerini kayda değer şekilde değiştirmediğini göstermektedir. Ancak, lipid oksidasyonunu etkili bir şekilde azaltır ve onların tekstürel niteliklerini artırır. Bu çalışma, sığır köftelerinin kalitesini artırmak için *B. vulgaris* ekstraktının doğal bir katkı maddesi olarak potansiyel kullanımını desteklemektedir.

1. INTRODUCTION

Adequate and balanced nutrition is essential for individuals to live healthily, develop economically and socially, and improve their overall well-being [1]. Among the vital nutrients, protein plays a crucial role, with meat and meat products being excellent sources of animal protein [2].. They are rich in essential amino acids and low in carbohydrates [3]. Additionally, meat is an excellent source of iron, zinc, selenium, niacin, vitamins A, B6, and B12, as well as essential fatty acids [4].

Beef patties are a traditional and popular food product with rich nutritional value and distinct flavor. However, due to factors such as processing, storage, and preservation methods, the quality of beef patties can be easily compromised, limiting their competitive position in the market [5]. Besides, suitable conditions for microorganisms, appropriate pH, high water activity, and the presence of unsaturated fatty acids, also contribute to the limited shelf life of beef patties, whether they are sold raw or partially cooked [6]. Therefore, attention must be given to every step of the production process to maintain product quality [5].

Lipid oxidation is one of the significant changes affecting the sensory properties of meat products, particularly in terms of flavor and texture, leading to a reduced shelf life. To extend shelf life and improve the overall quality of beef patties, various natural additives, spices, and plants are commonly used in the meat industry [7, 8]. In particular, the addition of natural antioxidants to meat products has become a key focus in recent research to enhancee oxidative stability and prevent microbial degradation [9, 10].

One such natural additive is *B. vulgaris*, a plant belonging to the Berberis genus of the Berberidaceae family. *B. vulgaris* is known for its red color and sour taste, and its fruit contains significant levels of antioxidant compounds that are beneficial for human health [11, 12]. This plant is commonly used in the food industry to produce jam, sweets, wine, and tea [13], and it has traditionally been used for medicinal purposes, particularly in treating kidney, urinary, and digestive disorders, as well as for improving circulation [14, 15].

In this study, *B. vulgaris* fruit extract was incorporated into beef patties as a natural antioxidant to assess its impact on the patties' physicochemical, sensory, and textural properties. The purpose of using *B. vulgaris* extract is to enhance the product's oxidative stability while preserving its nutritional and sensory characteristics. The study also aims to evaluate the extract's potential to improve the overall quality of beef patties.

2. MATERIAL AND METHOD

In the research, minced beef and beef fat obtained from a local butcher were used. *B. vulgaris* L. (barberry) fruit was collected from local gardens in Bayburt province. The minced beef and beef fat used in the study were brought to Bayburt University Aydıntepe Vocational School Department of Food Processing Laboratory under suitable conditions and stored at 4 °C until use as research material.

1.1. Preparation of Fruit Extract

100 grams of the fruit were weighed and dried in an oven at 50°C for two days. The dried fruit was then ground in porcelain mortars until it reached the desired grain size. Afterward, 100 mL ethanol (80%) was added to 10 g of sample and the mixture was left to extract for 48 hours in a water bath with temperature maintained below 40 °C. The extract was subsequently filtered and underwent evaporation in an evaporator. The obtained extract was dried in a lyophilizer and the fruit extract was prepared [16, 17].

1.2. Patties preparation and sampling

Minced beef and beef fat obtained from a local butcher were used in patty production at +4 °C. The fat proportion was set to 20% of minced beef, and a homogeneous mixture was obtained. The lyophilized extract was added to the mixture at rates of 0.1%, 0.2%, and 0.4%. The control group had no extract added. All groups had 1.5% salt added. The prepared mixtures were kneaded until homogeneous. The patties were shaped with a diameter of 9.0 ± 0.2 cm and a thickness of 1.0 ± 0.3 cm using Petri dishes. After shaping, the patties were left to rest at 4°C for 1 day. The weight of each patty was standardized to approximately 50 g. The patties, which had rested in the refrigerator, were cooked on a preheated heating plate set to 180°C for 12 minutes. During the cooking process, the patties were turned every two minutes.

1.3. Antioxidant Evaluations and Overall Phenolic Substance Content

The study employed three fundamental analysis methods to evaluate the antioxidant properties and total phenolic content of plant extracts. First, the DPPH analysis determined the extract's capacity to scavenge DPPH radicals, expressing antioxidant activity as Trolox equivalent (mg g^{-1}) based on the optical density measured at 517 nm [18]. Similarly, the ABTS analysis evaluated the extract's ability to reduce ABTS substrate, correlating the absorbance change at 734 nm with Trolox equivalent (mg g^{-1}) [19]. Additionally, the Folin–Ciocalteu phenol analysis determined the total phenolic components of the extract, presenting the results in terms of Gallic acid equivalent (mg g^{-1}) [20]. These analysis methods comprehensively assessed different aspects, including antioxidant capacity, radical scavenging ability, and total phenolic content, providing a detailed evaluation of the biological activity of plant extracts.

1.4. Physicochemical Analyses

Raw samples of patties from each group were analyzed for moisture [21], pH [22], ash [21], color, and thiobarbituric acid reactive substances (TBARS) [23]. Cooked patties from each group were analyzed for pH, TBARS, color, sensory analysis, and textural properties

after microbiological analyses were carried out. Additionally, the cooking yield of the patties was identified. Color values (L*, a*, b*) of the samples were determined using a Chroma Meter (CR-200, Minolta Co, Osaka, Japan) colorimeter. Color measurements were assessed according to the criteria determined by the Commission Internationale de l'E Clairage based on three-dimensional color measurements. Accordingly, color intensities are represented by L*; L*=0, black; L*=100 white (darkness/brightness); a*; +a*=red, -a*=green and b*; +b*=yellow, b*=blue. Before use, the device was calibrated with a standard calibration scale.
The following equation was used to identify cooking yield [24].

$$Cooking\ yield = \left(\frac{patties\ weight\ after\ cooking\ (g)}{patties\ weight\ before\ cooking\ (g)}\right) * 100 \quad (1)$$

1.5. Total Aerobic Mesophilic Bacterial Count (TAMB)

Seeding was performed with the plate count agar (PCA, Merck) spreading method, and samples were incubated under aerobic conditions for 2 days at 30 °C in Petri dishes. Count results were determined as log cfu g^{-1} at the end of incubation [25].

1.6. Enterobacteriaceae Count

For the detection of Enterobacteriaceae counts, seeding was performed using the spreading method on violet red bile dextrose (VRBD, Merck) agar. Plates were incubated under anaerobic conditions for 2 days at 30 °C. Red colonies larger than 1 mm were counted after incubation and were given as log cfu g^{-1} [26].

1.7. Sensory Analysis

For sensory analysis, patties were cooked for 12 minutes on a heating plate at 170-180 °C, turning them until the internal temperature reached 72 °C. A panel of 10 panelists conducted sensory assessments of the ready-to-eat cooked patty samples using the following hedonic scale (1-9) [27].

1.8. Texture Profile Analysis

Texture analysis was carried out using a device (CT3, Brookfield Engineering Laboratories, USA). Cylindrical samples taken from the patties (20 mm diameter, 10 mm height) underwent TPA analysis (conditions: pretest velocity 1 mm g^{-1}, test velocity and post-test velocity 2 mm g^{-1}, 5 s between first and second compression and compression rate 50%) at room temperature with two compression cycles using a 50 mm cylindrical probe. Textural parameters were calculated from the obtained force-time curves (hardness, adhesiveness, cohesiveness, springiness, chewiness, gumminess, and resilience) [28].

1.9. Statistical Analyses

In the study, four different extract proportions (control, 0.1%, 0.2%, and 0.4% fruit extract) were used as factors. The research was arranged and carried out with two repetitions using a randomized complete block design. Only beef samples were used in the study, and the statistical analysis was performed accordingly. The results underwent variance analysis, and the means of significant main effects and interactions were compared using Duncan's multiple comparison test (SPSS 20.0).

3. RESULTS AND DISCUSSION

In this study, the antioxidant potential of *B. vulgaris* fruit extract was measured as 25.45±0.35 mg TE g^{-1} using the DPPH method and 42.42±2.59 mg TE g^{-1} using the ABTS method (Figure 1). Significant variations in antioxidant values reported in the literature were observed. Och et al. [29] reported higher DPPH and ABTS values compared to our study, whereas Gündoğdu et al. [30], Özgen et al. [31], and Yıldız et al. [32] reported lower ABTS values compared to our findings. These variations suggest that antioxidant activity is influenced by various factors such as geographical origin, environmental conditions, growing season, soil type, and post-harvest processing methods. Specifically, the climate and soil conditions in different cultivation regions can significantly affect the phenolic compounds and antioxidant capacities of plants. Additionally, variations in post-harvest processing techniques and extraction methods can determine the effectiveness and quantity of these compounds.

The high antioxidant values obtained in our study indicate that the extraction conditions used were more effective in isolating antioxidant compounds. These results highlight the potential of *B. vulgaris* as a rich source of antioxidants and emphasize the contribution of phenolic compounds to its antioxidant capacity.

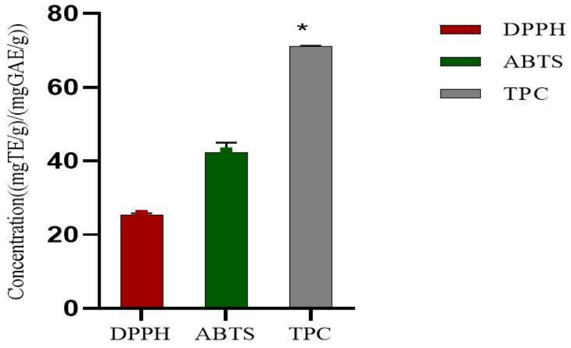

Figure 1. Antioxidant activity and total phenolic content of fruits

The total polyphenol content of *B. vulgaris* fruit in this study was determined to be 71.09±0.28 mg GAE g^{-1} as shown in Figure 1. Eroğlu et al. [33] reported lower and higher total phenolic contents in water and ethanol extracts, respectively. Similarly, Özgen et al. [31], Yıldız et al. [32], and Ersoy et al. [34] reported lower total phenolic contents compared to our study, while Motalleb et al. [35] reported higher phenolic content. These variations can be attributed to factors such as the geographical origin of the samples, environmental conditions, growing season, soil type, and post-harvest processing methods. For example, high UV radiation and low water stress in some regions may lead to an increase in phenolic compounds, while more humid and temperate climates in other regions may result in lower levels of these compounds [36, 37].

Our study found that *B. vulgaris* fruit extract has high antioxidant potential and total phenolic content of. These findings suggest that *B. vulgaris* is an important source of antioxidants and that phenolic compounds contribute significantly to its antioxidant capacity. Moreover, variations in antioxidant and total phenolic contents highlight the need for standardized methodologies to accurately compare these compounds across different studies and better understand the factors influencing their accumulation in *B. vulgaris*.
The physicochemical analysis results for the beef patties are presented in Table 1.

Table 1. Moisture, pH, ash, color, TBARS value, and cooking yield in raw and cooked beef patties (Mean ± SD)

		Ratio (%)				
		0	0.1	0.2	0.4	Sig
R	**Moisture (%)**	71.19±9.20a	63.13±0.47a	63.73±0.48a	64.94±0.35a	ns
C	**Moisture (%)**	55.21±0.51a	50.91±0.65a	54.90±4.99a	53.41±0.79a	ns
R/C Moisture (%) Interaction						**
R	**pH**	5.68±0.01c	5.62±0.01c	5.48±0.05b	5.32±0.06a	**
C	**pH**	5.91±0.01d	5.83±0.02c	5.71±0.01b	5.54±0.02a	**
R/C pH Interaction						**
R	**Ash (%)**	2.22±0.34a	1.29±0.55a	2.61±0.47a	1.94±0.59a	ns
C	**Ash (%)**	2.83±0.18a	2.76±0.11a	2.98±0.07a	2.75±0.06a	ns
R/C Ash (%) Interaction						*
R	**L^***	65.46±4.31b	59.96±5.59ab	54.68±5.86a	60.37±3.16ab	ns
C	**L^***	55.95± 1.77a	50.44± 7.56a	49.06±1.88a	51.88± 3.95a	ns
R/C L^* Interaction						ns
R	**a^***	25.61±1.92a	26.32±6.26a	25.87±4.95a	29.18±0.65a	ns
C	**a^***	23.09± 2.16b	17.46± 2.02a	17.49±0.96a	15.64± 3.77a	ns
R/C a^* Interaction						**
R	**b^***	13.68±0.68a	13.34±2.24a	12.39±1.72a	12.61±2.79a	ns
C	**b^***	9.40±1.38a	9.02± 1.58a	8.89±1.79a	8.89±2.74a	ns
R/C b^* Interaction						*
R	**TBARS (mgMDA/kg)**	1.95±0.04b	1.72±0.16b	1.53±0.08a	1.63±0.01a	**
C	**TBARS (mgMDA/kg)**	2.29±0.33a	1.72±0.36a	2.01±0.21a	1.86±0.14a	ns
R/C TBARS (mgMDA/kg) Interaction						ns
Cooking Yield (%)		75.72±1.22c	70.17±0.33b	68.87±0.72ab	67.41±0.57a	**

Sig (Significance), R (Raw), C (Cooked), SD (Standard Deviation), ** p<0.01, * p<0.05 (Significance Levels), ns (Non-significant for p>0.05), and different letters in the same column (a-c) indicating significant differences (p<0.05) are utilized.

As stated in the literature, the addition of the extract did not significantly alter the approximate composition of the patties, particularly with respect to moisture and ash content [6, 38]. These findings indicate that the extract's impact on the initial composition of the patties is limited. The observed loss of moisture during the cooking of patties aligns with a common outcome observed in meat and meat product cooking processes [39, 40].

However, the interaction between raw and cooked patties (R/C) showed significant changes in moisture retention, suggesting that the extract may influence the moisture retention capacity during cooking. Specifically, while the extract did not significantly alter the initial moisture content of the patties, it seems to modulate moisture loss during cooking, with a more pronounced effect seen in cooked patties. This finding supports the hypothesis that the addition of the extract may have an augmenting effect on moisture loss, particularly during cooking, and underscores the dynamic changes in composition that occur during the cooking process. Thus, the addition of the extract maintains the stability of the patties' composition while inducing changes in moisture content, particularly during cooking. The interaction between raw and cooked patties indicates that the extract may influence the extent of moisture loss in the final cooked product.

The pH values of raw patties exhibit a significant effect across all experimental groups (P<0.01), indicating that the addition of the extract significantly lowered the pH levels. This decrease can be attributed to the naturally low pH value (2.85) of *B. vulgaris*. The pronounced effect of the extract on the acidic properties of the raw patties demonstrates a significant alteration in the pH profile induced by the botanical extract. During the cooking process, the interaction on pH becomes more complex, and a pronounced change is observed in all groups (P<0.01). This indicates how the extract interacts with the initial pH of the raw materials and the changes occurring during cooking. The extract appears to play a role in shaping the acidity profile in raw patties during cooking, with this effect becoming more pronounced in the cooked patties. Furthermore, instead of the expected pH increase during cooking [41, 42], a lower pH value was observed in the raw patties, suggesting that the acidic components of the extract become more pronounced during cooking. Although an increase in pH during cooking is generally expected in meat [41, 42], the low pH of *B. vulgaris* has been shown to alter this expectation. The low pH of the extract influences the acidity profile in both raw and cooked patties, creating a more acidic environment during the cooking process. These findings emphasize the role of the botanical extract in this interaction and contribute to our understanding of its effects on acidity control throughout the cooking process. In conclusion, the pH interaction between raw and cooked patties shows that the addition of the extract not only influences the initial pH levels but also shapes the changes in acidic properties during cooking. This suggests a more dynamic interaction with pH during cooking and highlights the extract's significant influence on this process.

The TBARS values of raw patties exhibited a significant impact in all groups ($P<0.05$). The presence of antioxidants and phenolic components in the extract reduced lipid oxidation and free radical formation, thereby enhancing the product's antioxidant capacity. An increase in the extract proportion resulted in lower TBARS values compared to the control group. These findings align with studies conducted by Ahn and Grün [43], Mahapatra et al., [44], and Erdoğan and Özdestan-Ocak [38]. During the cooking process, no significant difference was observed between TBARS values ($p>0.05$). This suggests that the cooking procedure did not influence TBARS values. However, it is important to note that the interaction between the raw and cooked patties revealed dynamic changes in TBARS values. While no significant differences were observed during cooking, the antioxidant properties of the extract in the raw patties still effectively mitigated lipid oxidation and free radical formation. This suggests that the extract's role in controlling lipid oxidation is most prominent in the raw patties, with its impact on TBARS values remaining stable throughout the cooking process. These results affirm that the low TBARS values in raw patties can be attributed to the antioxidant properties of the extract, effectively mitigating lipid oxidation and free radical formation. The interaction highlights that while the extract reduces lipid oxidation in raw patties, its effect does not change significantly during cooking, suggesting that the antioxidant capacity is retained during thermal processing. These findings underscore the significant potential of plant extracts in enhancing the quality of raw patties while maintaining their antioxidant efficacy during cooking.

Although no statistically significant differences were observed in color values, cooking resulted in a notable decrease in L*, a*, and b* values. These color changes can be attributed to biochemical processes, such as an increase in metmyoglobin concentration or myoglobin denaturation. The findings align with similar results in the literature, supporting the impact of decreases in color values during cooking on meat pigments [8]. During cooking, a significant interaction between raw and cooked patties was observed, leading to changes in color parameters. While no significant differences were found between groups, the cooking process affected the color properties of the patties, with a decrease in L*, a*, and b* values. This suggests that the extract may modulate color changes during cooking, possibly influencing myoglobin stability or the rate of metmyoglobin formation. The interaction between raw and cooked patties highlights the dynamic nature of color changes during cooking, which could have implications for the visual properties of the product. Considering that color changes directly affect the visual and sensory characteristics of a product, these findings emphasize the importance of understanding the physical and chemical transformations occurring during the cooking process. Ultimately, the study contributes valuable insights into the potential effects of color changes during cooking on product quality. The interaction findings suggest that cooking not only affects color values but also influences the extract's role in color stability during the process.

The cooking of meat is a crucial step for flavor enhancement. Microbiological analyses play a pivotal role in evaluating the microbiological quality of the product, aligning with product specifications or legally applicable standards [45]. In this study, microbiological analyses indicated that the total aerobic mesophilic bacteria and Enterobacteriaceae counts were below the detectable limit (<2 log cfu g^{-1}) after the cooking process. The microbiological results underscore the notion that the cooking process enhances microbiological quality, contributing significantly to the overall quality of the product. The use of extract is believed to potentially contribute to maintaining microbial stability. This aspect holds particular importance for the product's consequently and consumer health. However, a more detailed analysis is warranted to elucidate the specific effects of the extract on microbiological stability. Further investigation into how the extract may exert antimicrobial effects and impact microbial growth would provide valuable insights. Such in-depth analyses can inform specific strategies to maintain and improve the microbiological quality of the product.

Cooking yield is a critical parameter for evaluating quality changes in meat products during the cooking process [46]. In this study, a significant reduction in cooking yield ($P<0.01$) was observed in patties formulated with Berberis extract. This result may be attributed to the extract's potential to enhance fat and moisture loss during cooking. The literature frequently highlights the influence of additive composition and thermal properties on cooking yield [47].

The reduction in cooking yield caused by Berberis extract suggests that it may limit water and fat binding capacity, affecting the stability of the protein matrix. This finding contrasts with the results of Naveena et al. [48], who reported that additives improved cooking yield in chicken burgers. Differences between studies could arise from variations in the chemical composition of the extract, the type of meat, and the applied processes.

The results underscore the need for further investigation into the effects of Berberis extract on fat and moisture loss. Future research could guide the development of novel formulations to optimize these effects.

The sensory analysis results for the beef patties were given in Figure 2.

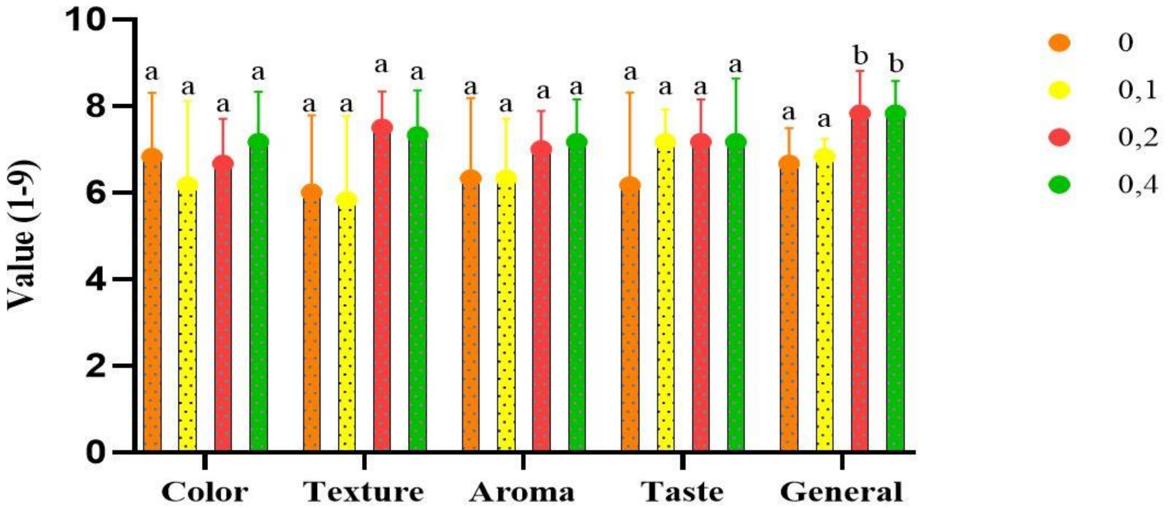

Figure 2. The sensory analysis results for the beef patties.

The columns in the table represent the mean of three replicates, and the vertical bars indicate the standard error of the mean. Distinct letters denote statistically significant variances based on Duncan's multiple range test ($p < 0.05$).

The addition of the extract did not result in significant changes in the sensory characteristics of the patties. However, according to the panelists' evaluations, an improvement in sensory properties was observed as the extract proportion increased. Although no statistically significant differences were found, these observations suggest that the extract may have a subtle but positive effect on sensory profiles such as flavor, aroma, and texture. Similarly, in a study by Naveena et al. [49], plant extracts showed a tendency for improved flavor and texture profiles as extract concentrations increased, although no statistically significant differences were found. These findings are consistent with the data from our study, where a trend of improvement in sensory characteristics was observed with an increase in extract proportion, despite the lack of statistical significance. Additionally, Bouarab-Chibane et al. [50] reported that plant extracts had varying effects on sensory characteristics such as color, texture, and taste. While some extracts led to distinct sensory changes, others did not result in meaningful differences in sensory perception. This is in line with our findings, suggesting that plant extracts have the potential to improve sensory attributes, with the degree of impact varying depending on the extract type and concentration.

Texture analysis results for the beef patties are presented in Table 2.

Table 2. Texture analysis results (Mean ± SD)

	Raito (%)				
	0	0.1	0.2	0.4	Sig
Hardness (N)	62.49±6.89a	72.29±8.87ab	88.78±7.016c	82.40±5.013bc	**
Adhesiveness (mJ)	0.40±0.29a	0.30±0.13a	0.13±0.14a	0.13±0.15a	ns
Resilince	0.24±0.015a	0.28±0.01a	0.26±0.022b	0.25±0.01ab	ns
Cohesiveness	0.52±0.01a	0.55±0.05a	0.60±0.03b	0.56±0.03ab	ns
Springeness (mm)	9.24±0.48a	9.10±0.59a	9.06±0.44a	9.44±0.68a	ns
Gumminess (N)	32.56±3.07a	40.54±9.01ab	53.65±5.64c	46.03±3.16bc	**
Chewiness (mJ)	299.82± 14.19a	358.90±53.01a	485.85±57.78b	433.50±30.30b	**

Sig (Significance), SD (Standard Deviation), ** $p<0.01$, * $p<0.05$ (Significance Levels), ns (Non-significant for $p>0.05$), and different letters in the same column (a-c) indicating significant differences ($p<0.05$) are utilized.

The effects of different concentrations of *B. vulgaris* extract on the texture properties of meatballs were investigated. Significant statistical differences in hardness, gumminess, and chewiness values were observed across all groups ($P<0.01$). An increase in extract concentration resulted in a notable rise in the hardness, gumminess, and chewiness values of the meatball samples. These findings suggest that Berberis vulgaris extract has a reinforcing effect on the protein matrix. Plant polyphenols can interact with proteins, forming cross-links that may enhance the structural integrity of the meatballs [51]. However, variability in the mechanisms of action of different plant extracts has been observed in the literature. For example, in the study by Mahapatra et al. [52], it was reported that certain fruit extracts reduced the hardness of meat products. On the other hand, Salejda et al. [53] reported that the addition of cherry cornis juice had an increasing effect on the hardness of model beef meatballs. These differences may be attributed to the chemical composition of the extracts, application ratios, and the physicochemical properties of the meat product [54].

The increase in gumminess and chewiness values may be linked to the extract's capacity to enhance the mechanical stability of the meatballs. The extract's effect of increasing water and fat loss during cooking may have contributed to the formation of a denser protein matrix, thereby improving gumminess and chewiness. Additionally, the phenolic compounds in plant extracts may strengthen protein-protein interactions, creating a tighter structure that further enhances these properties. Literature on the effects of plant extracts on gumminess and chewiness shows varied results. For instance, Choi et al. [55] found that increasing lotus leaf powder levels from 1% to 3% led to a significant decrease in the hardness, stickiness, and chewiness values of chicken meatballs.

These findings suggest that *B. vulgaris* extract has the potential to improve the texture properties of meatballs. The results of this study highlight the practical potential of using Berberis vulgaris extract as a natural food additive. Future research could further explore the effects of varying extract concentrations and evaluate their impact on sensory properties.

4. CONCLUSION

This study investigated the effects of *B. vulgaris* extract on the physicochemical, sensory, and textural properties of beef patties. The results demonstrated that while the extract did not significantly alter the moisture, ash content, or color, it reduced lipid oxidation (TBARS values) and enhanced textural parameters such as hardness, gumminess, and chewiness. However, the extract caused a significant reduction in cooking yield, potentially due to its effect on fat and moisture retention.

These findings suggest that *B. vulgaris* extract can be utilized as a natural antioxidant in meat products, contributing to oxidative stability and textural improvements. Further studies are necessary to optimize extract concentrations and minimize adverse effects on cooking yield. Additionally, exploring its interaction with other additives and its impact under different cooking conditions could broaden its industrial application. This research highlights the potential of *B. vulgaris* extract as a sustainable alternative to synthetic additives, paving the way for healthier and more natural meat products.

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