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Berberis Fruit Extracts in Marinated Meat: Quality Effects

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ABSTRACT

In this study, the effects of the fruit extracts *Berberis vulgaris* L. and *Berberis crataegina* DC. on the quality of the meat were evaluated. According to the results of antioxidant activity analyses, the antioxidant activities of *B. vulgaris* and *B. crataegina* fruit extracts were determined as 81.29 ± 14.14% and 78.97 ± 0.39%, respectively. The phenolic content of *B. vulgaris* fruit extract was found to be 1707.88 ± 60.10 mg GAE/g, while the phenolic content of *B. crataegina* fruit extract was 83.64 ± 1.61 mg GAE/g ($p<0.01$). These differences indicate significant diversity in phenolic compounds among plant species. pH values of meat samples marinated with *B. vulgaris* extract showed a gradual decrease over time. For instance, at the 3rd hour, the pH value of meat samples marinated with *B. vulgaris* was determined as 4.42 ± 0.05 ($p<0.01$). At the end of storage, TBARS values were determined as (1.54±0.13; 0.41±0.11; and 0.19±0.02 mg MDA/kg) in the control, *B. crataegina* and *B. vulgaris* groups, respectively ($p<0.01$). A significant reduction in Total Aerobic Mesophilic Bacteria (TAMB) count was observed in meat samples marinated with *B. vulgaris* extract. For example, at the end of the 12th day, the TAMB count was determined as 8.95 ± 0.07 log CFU/g in the control group, while it was 5.74 ± 0.06 log CFU/g in meat samples marinated with *B. vulgaris* extract ($p<0.01$). These data demonstrate the potential of *Berberis vulgaris* and *Berberis crataegina* fruit extracts to improve meat quality. With their antioxidant activities, phenolic contents, pH effects, and microbial inhibition, these extracts can be considered important natural components to use in the meat industry.

Keywords: Antioxidant activity, *Berberis crataegina* DC., *Berberis vulgaris* L., Marination, Meat quality, Phenolic content.

Berberis Meyve Ekstresi ile Marine Edilmiş Et: Kalite Üzerindeki Etkiler

ÖZ

Bu çalışmada, *Berberis vulgaris* L. ve *Berberis crataegina* DC. meyve ekstraktlarının et kalitesi üzerindeki etkileri değerlendirilmiştir. Antioksidan aktivite analizleri sonuçlarına göre, *B. vulgaris* ve *B. crataegina* meyve ekstraktlarının antioksidan aktiviteleri sırasıyla %81.29 ± 14.14 ve %78.97 ± 0.39 olarak belirlenmiştir. *B. vulgaris* meyve ekstraktının fenolik içeriği 1707.88 ± 60.10 mg GAE/g, *B. crataegina* meyve ekstraktının fenolik içeriği ise 83.64 ± 1.61 mg GAE/g olarak bulunmuştur ($p<0.01$). Bu farklılıklar, bitki türleri arasında fenolik bileşiklerde önemli bir çeşitlilik olduğunu göstermektedir. *B. vulgaris* ekstraktı ile marine edilen et örneklerinin pH değerleri zamanla kademeli olarak azalmıştır. Örneğin, 3. saatte *B. vulgaris* ile marine edilen et örneklerinin pH değeri 4.42 ± 0.05 olarak belirlenmiştir ($p<0.01$). Depolamanın sonunda, TBARS değerleri kontrol, *B. crataegina* ve *B. vulgaris* gruplarında sırasıyla 1.54±0.13; 0.41±0.11; ve 0.19±0.02 mg MDA/kg olarak belirlenmiştir ($p<0.01$). B. vulgaris ekstraktı ile marine edilen et örneklerinde Toplam Aerobik Mezofilik Bakteri (TAMB) sayısında önemli bir azalma gözlenmiştir. Örneğin, 12. günün sonunda kontrol grubunda TAMB sayısı 8.95 ± 0.07 log CFU/g olarak belirlenirken, *B. vulgaris* ekstraktı ile marine edilen et örneklerinde bu değer 5.74 ± 0.06 log CFU/g olarak belirlenmiştir ($p<0.01$). Bu veriler, *Berberis vulgaris* ve *Berberis crataegina* meyve ekstraktlarının et kalitesini iyileştirme potansiyelini göstermektedir. Antioksidan aktiviteleri, fenolik içerikleri, pH etkileri ve mikrobiyal inhibisyonları ile bu ekstraktlar, et endüstrisinde önemli doğal bileşenler olarak değerlendirilebilir.

Anahtar Kelimeler: Antioksidan aktivite, Berberis crataegina DC., Berberis vulgaris L., Marinasyon, Et kalitesi, Fenolik içerik.

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1. Introduction

Marination was considered one of the treatments to enrich meat quality (Latoch et al., 2023). It was revealed that marination increases beef tenderness and/or cooking efficiency (Kim et al., 2014; Gómez et al., 2020). Some studies also reported the effectiveness of marination in enhancing meat tenderization and flavor (Scanga et al., 2000; Burke and Monahan, 2003; Lunde et al., 2008). Ingredients generally used for marination in meat products consist of water, salt, and alkaline phosphates. Moreover, natural flavorings are used in marination solutions due to their strong antioxidative properties (Ehsanur Rahman et al., 2023). To improve meat tenderness, diverse strategies, including chemical and mechanical methods, are employed. However, consumers nowadays are increasingly demanding clear labeling for products, including meat, and insisting on production methods free from preservatives or synthetic components (Latoch et al., 2023).

In recent times, it has been known that the antioxidant and antimicrobial effects of various plant extracts play significant roles in human health (Deveci and Özaslan, 2022). The antioxidant capacity of meat is very low. Therefore, the antioxidant capacity of meat was increased by adding plant parts (such as seeds, fruit skin or peel, and flowers) rich in flavonoids to the meat during processing (Kumar et al., 2013). Some studies found that using spices, herbs, dry red wine, and honey-lime combinations in meat marination increases the product's polyphenol and flavonoid contents and antioxidant activity (Istratı et al., 2012). Recent studies have focused on natural antioxidant sources, antioxidant compounds, the relationship between antioxidants and health, and the effects of antioxidants on food quality.

Numerous plant species belonging to the genus Berberis (Berberidaceae) possess a variety of nutritional and phytochemical components extensively utilized in the food and pharmaceutical sectors (Yin et al., 2023). *B. vulgaris* and *B. crataegina* are two significant species within the Berberis genus of the Berberidaceae family (Deveci and Özaslan, 2022). Berberis varieties are renowned for their functional and nutraceutical attributes. Various species of Berberis have demonstrated diverse pharmacological activities and found utility in the food sector as additives, preservatives, and antioxidants (Ali Redha et al., 2021).

This study investigated the use of *B. vulgaris* and *B. crataegina* to enhance the shelf life and quality of meat. For this purpose, the antioxidant and phenolic substance capacities of *B. vulgaris* and *B. crataegina* were initially determined. Then, the physicochemical and sensory properties of meat marinated using Berberis extracts were investigated during storage.

2. Material and Method

2.1. Material

The fruits of *B. vulgaris* and *B. crataegina* were obtained from mountainous areas far from the city center and located in the province of Bayburt in September and October 2021. This description was provided by Cakir, one of the authors. The beef thigh muscle obtained from the local butcher was used for marinating.

2.2. Method

2.2.1. Extraction Process of Fruit

The extraction of the fruits was conducted by modifying the method given by Karabegović et al. (2014). One hundred grams of *B. vulgaris* and *B. crataegina* fruits were taken and left to dry in an oven at 50 ºC for 1-2 days. Then, the dried fruits were ground using porcelain mortars to preserve the fruit properties (antioxidant activity, phenolic substance, etc.). This process was continued until the appropriate particle size was reached. Ten grams of the powdered sample were added to 100 ml of an 80% ethanol mixture. The mixture was extracted in a water bath (WiseClean) at a constant temperature of 40 ºC for 48 hours. Then the extract was filtered with plain filter paper and evaporated at 40 ºC under low pressure with the help of an evaporator. In this way, ethanol was

removed, and it was dried in a lyophilizer to obtain ethanol extract. As a result, the prepared lyophilized extracts were stored at -80 ºC until marination.

2.2.2. DPPH (2,2-diphenyl-1-picrylhydrazyl) Radical Scavenging Capacity

The samples' antioxidant activity was determined at 515 nm by modifying the method presented by Gülçin (2005). The % inhibition was calculated using the absorbance value (1).

$$\% \text{ Inhibition} = \left[\frac{A_{DPPH} - A_{extract}}{A_{DPPH}}\right] * 100 \quad \textbf{(1)}$$

A_{DPPH}: Absorbance value of the blank

$A_{extract}$: Absorbance value of the sample

2.2.3. Phenolic Content

Analysis was conducted following the method outlined by Singleton and Rossi (1965). One milliliter of each fruit extract was transferred to test tubes, and 5 ml of 0.2 N Folin-Ciocalteu reagent (FCR) was added. Subsequently, 4 ml of 7.5% Na_2CO_3 solution was introduced to each tube, and absorbance was measured at 760 nm after incubating the tubes in the dark at room temperature for 90 minutes.

Solutions were prepared using gallic acid at concentrations ranging from 1 to 1000 mg/ml, and a standard curve was generated by employing the same procedures. The obtained equation was utilized in the calculations. The results are expressed as gallic acid equivalent (mg GAE/g).

2.2.4. Preparation of Meat Samples

The marination process was carried out by modifying the method provided by Aliakbarlu and Mohammadi (2015). Thigh muscle meat was collected within 5-6 hours after slaughter, immediately cooled, and transported to the laboratory. After visible fat and connective tissues were removed aseptically, the meat was cut into cubed pieces. The cubed meat was divided into three equal (1000 g) groups: control (0% extract), *B. vulgaris*, and *B. crataegina*. Both extracts were added to the meat separately at a 3% (w/w) level and placed in stomacher bags. Subsequently, all groups were stored under aerobic conditions at 4±1 ºC for 12 days.

2.2.5. Moisture

10 g of the sample were weighed into a nickel cup and dried at 100-102 °C until the samples reached constant weight (18-24 hours), and then the result was calculated as %.

2.2.6. pH

To assess the pH of meat samples, 100 ml of distilled water was added to 10 grams of the sample and homogenized for 1 minute using an Ultra-Turrax (IKA Werk T 25, Germany). The pH of the homogenized samples was then measured with a pH meter (OHAUS, ST2100, Switzerland). The pH meter underwent calibration using suitable buffer solutions (pH 4.00 and pH 7.00) before utilization.

2.2.7. Water Activity (a_w)

The samples' water activity (a_w) was measured at 25 °C using a device (NOVASINA TH-500 aw Sprint, Switzerland).

2.2.8. Color Values

Meat sample color values (L*, a*, b*) were determined using a Chroma Meter (CR-200, MinoltaCo, Osaka, Japan) colorimeter. L* indicates darkness/lightness (L* = 0 is black, L* = 100 is white), a* represents redness (+a*) or greenness (-a*), and b* signifies yellowness (+b*) or blueness (-b*), based on three-dimensional color measurement by the Commission Internationale de l'Eclairage criteria.

2.2.9. Thiobarbituric Acid Reactive Substances (TBARS)

The TBARS value of beef pattie samples was determined according to the method described by Lemon (1975). Two grams of beef pattie samples were taken, and 12 ml of TCA solution (7.5% TCA, 0.1% EDTA, 0.1% propyl gallate; where 1 gram of propyl gallate is dissolved in 3 ml of

ethanol) was added. The mixture was homogenized using an Ultra-Turrax and filtered through Whatman No: 1 filter paper. One milliliter of the filtrate was taken into a tube, and 1 ml of TBA solution (0.02 M) was added. The prepared mixtures were kept in a boiling water bath for 40 minutes and then cooled down. After that, they were centrifuged at 2000 x g for 5 minutes. The absorbance of the samples was measured at 532 nm wavelength against a blank sample. The TBARS value was expressed as mg malondialdehyde/kg of beef pattie.

2.2.10. Total Aerobic Mesophilic Bacteria (TAMB) and Enterobacteriaceae

For TAMB count determination, PCA (Plate Count Agar, Merck) was inoculated via the spread plate method and incubated aerobically at 30 °C for 2 days. Results were expressed in log CFU/ml. Enterobacteriaceae count was determined on VRBD (Violet Red Bile Dextrose, Merck) Agar using the spread plate method, followed by anaerobic incubation at 30 °C for 2 days. Red colonies larger than 1 mm were counted, and the result was expressed as log CFU/ml.

2.2.11. Sensory Analysis

After marination (24 h), the samples were drained of excess water, placed in, bags and cooked by immersion in a water bath at 80 °C. The samples were cooled in a water tank for 10 minutes (Burke and Monahan, 2003). The ready-to-eat cooked samples were evaluated for taste, aroma, texture, and overall flavor by expert panelists using a hedonic scale (1-9). As scores approach 9, it indicates that the sensory attribute is of higher quality.

2.2.12. Statistical Analysis

In the present study, two marination processes (control and 3,0% fruit extract) were taken as factors, and the research was conducted in two replications according to a randomized complete blocks trial design. The analysis of variance was applied to the results obtained, and the averages of the main sources of variation found significant ($p \leq 0.01$) were compared by Duncan's multiple comparison test using the SPSS statistical software (version 20.0).

3. Results and Discussion

3.1. Antioxidant Activity and Total Phenolic Content of Fruits

Antioxidants exert their effects by scavenging free radicals, disrupting chain reactions, decomposing peroxides, decreasing localized oxygen concentration, and binding chain-initiating catalysts (Hugo and Hugo, 2015). The antioxidant activities of *B. vulgaris* and *B. crataegina* fruit extracts were above 75% in the present study (Table 1).

In the studies carried out, *B. vulgaris* extract has been reported to have high antioxidant properties, with values of 40.75% (Aliakbarlu et al., 2018) and 34.38% (Eroğlu et al., 2020). Similarly, Asadi et al. (2019) reported a high antioxidant activity of 69.56% in the fruit juice extract of *B. vulgaris*. In this study, similar results were obtained as reported in the literature.

Table 1. Antioxidant activity and total phenolic content of fruits

	Antioxidant activity (% inhibition)	Total phenolic content (mg GAE/g)
B. crataegina	78.97±0.39[a]	1707.88±60.10[a]
B. vulgaris	83.64±1.61[a]	812.88±14.14[b]

The presented values are mean ± SD; a-b, any two means in the same row having the same letters are not significantly different. SD: standard deviation.

Barberry species contain a rich array of active substances, including anthocyanins, flavonoids, proteins, terpenoids, antioxidants, lignans, vitamins, carotenoids, tannins, organic, and phenolic acids. Barberry fruits, particularly abundant in antioxidants, boast diverse phenolic compounds like apigenin, rutin, quercetin, chlorogenic acid, caffeic acid, and anthocyanins (Moghadam et al., 2018). In this study, the polyphenol contents of *B. vulgaris* and *B. crataegina* fruits were determined as 812.80 and 1707.88 mg GAE/g, respectively (Table 1). In the study by Aliakbarlu et al. (2018), different solvents were used for obtaining *B. vulgaris* extract, and the total phenolic content in ethanol extraction was determined as 49.92 mg GAE/g. In this study, the use of *B. vulgaris* fruit in marination resulted in higher total phenolic content and % radical scavenging activity, indicating a higher antioxidant effect of this fruit. According to a study by Çakır and Karabulut (2020), the total phenolic content of *B. crataegina* fruit extracts was determined to be 73.48 µg GAE/mg, while the total phenolic content of *B. vulgaris* fruit extracts was 71.54 µg GAE/mg. In a study by Eroğlu et al. (2020), the total phenolic content was found to be 148.00 µg GAE/mg in aqueous *B. vulgaris* extract and 448.30 µg GAE/mg in ethanol *B. vulgaris* extract. In a study by Aliakbarlu et al. (2018), the highest total phenolic content was found to be 92.75 mg GAE/g in acetone *B. vulgaris* extract and 49.92 mg GAE/g in ethanol *B. vulgaris* extract.In the literature, different results were obtained in terms of total phenolic content depending on the geographical regions where barberry fruits were harvested, environmental and climatic conditions, growing season, soil type, storage and processing conditions (Aliakbarlu et al., 2018; Eroğlu et al., 2020; Çakır and Karabulut, 2020). According to the statistical results, the total phenolic content of two fruits (*B. vulgaris* and *B. crataegina*) showed a very significant difference ($p<0.01$). These results may support the potential use of Berberis species in functional food and nutrition fields. Furthermore, they could encourage further research to better understand the biological activities of these plants and evaluate their health benefits.

3.2. Moisture, a_w, pH, and Color Values

As observed in Table 2, the use of different plant extracts in meat marination did not have a significant effect on moisture content. There was no statistically significant difference in moisture content among meat samples marinated with 3% concentrations of *B. crataegina* and *B. vulgaris* plant extracts during storage. After 24 hours, the moisture content of the control group was found to be lower, which was statistically different from the treatment groups (84.91 ±6.00 % for *B. crataegina* and 80.09 ±0.09 % for *B. vulgaris*). In a study by Aktaş et al. (2003) investigating the effects of organic acid marination on beef content, bound water, cooking loss, and tenderness, lower moisture content was observed in the control group compared to samples treated with different concentrations of organic acid. In another study investigating the effect of marination with fruit and vegetable juices on some characteristic properties of Turkey breast meat, it was found that the moisture content of control samples increased during marination and then decreased, while the moisture content of marinated samples showed the opposite trend (Gök and Bor, 2016). The obtained results are consistent with the literature, indicating that marination with plant extracts had no significant effect on moisture content in meat samples, aligning with previous findings in similar studies.

Water activity is a better indicator than moisture content for the sensory properties, stability, and microbial growth of meat and meat products. However, other factors such as oxygen concentration, water mobility, pH, and types of soluble substances also influence microbial growth and food stability (Fennema and Carpenter, 1984).

As seen in Table 2, the water activity (aw) values measured at 3 hours, 12 hours, and at the end of marination range from 0.978 to 0.983. These values align with the water activity of fresh meat (0.98-0.99) as reported by Fennema and Carpenter

(1984). The highest aw value was observed in the group marinated with *B. vulgaris* at 12 hours of marination, with no statistically significant difference observed among the groups.

Table 2. Moisture and a_w values of marinated meat samples

Time	Moisture values		
	Control	***B. crataegina***	***B. vulgaris***
3rd h	75.24 ± 1.92^{Aa}	78.30 ± 0.86^{Aa}	77.91 ± 1.25^{Aa}
12th h	75.30 ± 0.68^{Aa}	77.87 ± 0.45^{Aa}	78.64 ± 2.26^{Aa}
24th h	75.48 ± 0.19^{Aa}	84.91 ± 6.00^{Ab}	80.09 ± 0.09^{Ab}
Time	**Storage time**		
	Control	***B. crataegina***	***B. vulgaris***
3rd h	0.98 ± 0.00^{Aa}	0.98 ± 0.00^{Ab}	0.98 ± 0.00^{Aa}
12th h	0.98 ± 0.00^{Aa}	0.98 ± 0.00^{Aa}	0.98 ± 0.00^{Aa}
24th h	0.98 ± 0.00^{Aa}	0.98 ± 0.00^{Aa}	0.98 ± 0.00^{Aa}

The presented values are mean ± SD; a-b and A, any two means in the same row having the same letters are not significantly different. SD: standard deviation.

The pH of the fresh meat used as a material was determined as 5.65. Table 3 contains the pH values measured from the marination to the 12th day of storage. Different fruit extracts had a statistically significant effect on the samples' pH value ($p<0.01$). Barberry fruits contain various substances, such as carbohydrates, organic acids, vitamins, phenolic compounds, pectin, tannin, and minerals. Furthermore, barberry fruits were shown as acidic products since they contain organic acids such as malic acid, citric acid, and tartaric acid (Aliakbarlu et al., 2018). Thus, the pH value of barberry fruits varies between 2.44 and 3.25 (Eroğlu et al., 2020). In this regard, in the current study, it was thought that the decrease in pH value in the groups marinated with *B. crataegina* and *B. vulgaris* was due to the organic acids in the content of these fruits. In a study by Aktaş et al. (2003), the pH values of meat samples treated with different concentrations of various organic acids were found to be lower compared to the control group. Similarly, in a study by Gök and Bor (2016), a significant decrease in pH values was observed in the marinated groups, except for the control group, after 24 hours of marination.

Table 3. pH values of marinated meat samples

Time	Control	*B. crataegina*	*B. vulgaris*
3rd h	5.63 ± 0.01^{Bc}	4.93 ± 0.14^{BCb}	4.42 ± 0.05^{Ba}
12th h	5.54 ± 0.00^{Ac}	4.86 ± 0.09^{BCb}	4.37 ± 0.06^{Ba}
24th h	5.63 ± 0.01^{Bc}	5.05 ± 0.04^{Cb}	4.36 ± 0.04^{Ba}
4th day	5.61 ± 0.04^{Bc}	4.74 ± 0.03^{ABb}	4.08 ± 0.01^{Aa}
8th day	6.24 ± 0.04^{Cc}	$4.76\pm0.03_{ABb}$	4.13 ± 0.02^{Aa}
12th day	6.66 ± 0.01^{Dc}	4.64 ± 0.01^{Ab}	4.11 ± 0.01^{Aa}

The presented values are mean ± SD; a-c and A-C, any two means in the same row having the same letters are not significantly different. SD: standard deviation.

As seen in Table 4, while the use of different fruit extracts in marination did not affect the L* value ($p<0.01$), it had a significant effect ($p<0.01$) on the a* value and a significant effect ($p<0.01$) on the b* value at the end of the 24th hour. Additionally, on days 8 and 12 of storage, the b* value in the control group was lower than the other groups and showed a statistical difference ($p<0.01$). The incorporation of fruit extracts in the marinating solution had a significant effect ($p<0.01$) on the L* value on days 4, 8, and 12 of storage ($p<0.01$). The lowest mean a* value was determined from the 3rd hour to the end of the 12th day in the groups marinated with *B. vlgaris.*

It was thought that the acidity of *B. vulgaris* fruit might cause a change in the color intensity of the meat. Thus, treatment with acid can promote the conversion of myoglobin to metmyoglobin, resulting in lower color intensity. Furthermore, a decrease in pH value due to treatment with acid may cause the denaturation of sarcoplasmic and myofibrillar proteins, which may affect the water-holding ability of proteins. Furthermore, the amount of water dispersed between the muscle fibers changes the reflective properties of the meat (Aktaş and Kaya, 2001).

Table 4. Color values of marinated meat samples

Time		Control	*B. crataegina*	*B. vulgaris*
3rd h	**L***	42.52 ± 2.48^{Cb}	35.15 ± 1.79^{Aab}	30.59 ± 6.03^{Aa}
	a*	23.98 ± 1.75^{Cb}	14.79 ± 0.84^{Aa}	13.00 ± 1.73^{Ba}
	b*	10.91 ± 3.01^{Ba}	10.88 ± 0.64^{Aa}	7.62 ± 0.63^{Aa}
12th h	**L***	44.73 ± 0.29^{CDa}	46.26 ± 2.05^{Ba}	44.32 ± 1.01^{Ba}
	a*	22.40 ± 4.45^{Cb}	19.24 ± 1.12^{Cb}	13.63 ± 0.78^{Ba}
	b*	12.41 ± 1.08^{Cab}	14.02 ± 1.39^{Bb}	10.84 ± 0.49^{Ba}
24th h	**L***	45.63 ± 0.38^{Da}	46.24 ± 2.49^{Ba}	42.78 ± 4.35^{Ba}
	a*	21.33 ± 1.18^{Cc}	17.53 ± 0.72^{Bb}	12.49 ± 0.61^{Ba}
	b*	11.49 ± 1.08^{BCa}	14.23 ± 1.12^{Bb}	10.87 ± 0.81^{Ba}
4th day	**L***	44.71 ± 0.56^{CDb}	36.47 ± 1.33^{Aa}	44.02 ± 3.39^{Bb}
	a*	10.02 ± 0.66^{Aa}	14.80 ± 0.89^{Ab}	8.81 ± 1.48^{Aa}
	b*	10.81 ± 0.85^{BCa}	11.38 ± 1.01^{Aa}	11.60 ± 0.96^{Ba}
8th day	**L***	37.62 ± 0.58^{Ba}	34.09 ± 3.09^{Aa}	44.58 ± 0.77^{Bb}
	a*	14.81 ± 1.22^{Bb}	14.50 ± 1.18^{Ab}	8.81 ± 1.52^{Aa}
	b*	4.58 ± 0.25^{Aa}	12.07 ± 0.93^{Ab}	11.22 ± 1.65^{Bb}
12th day	**L***	32.36 ± 1.22^{Aa}	37.94 ± 0.84^{Ab}	45.63 ± 0.94^{Bc}
	a*	13.57 ± 0.55^{ABb}	15.90 ± 0.87^{ABc}	9.47 ± 0.83^{Aa}
	b*	3.44 ± 0.59^{Aa}	12.21 ± 0.21^{Ab}	12.38 ± 0.49^{Bb}

The presented values are mean ± SD; a-c and A-D, any two means in the same row having the same letters are not significantly different. SD: standard deviation.

3.3. TBARS

Lipid oxidation is an important problem for the meat and fish industry because it causes an undesirable rancid taste and toxic reaction products (Mohan et al., 2022). From the 24th hour, the groups had a significant effect on TBARS values ($p<0.01$). As seen in Table 5, compared to the control group, lower TBARS values in the groups marinated with *B. crataegina* and *B. vulgaris* were determined from the 24th hour. The TBARS value increased in all groups on days 4, 8, and 12 of storage. At the end of the storage, TBARS values were determined in the control, *B. crataegina,* and *B. vulgaris* groups as 1.54±0.13; 0.41±0.11 and 0.19±0.02 mg MDA/kg, respectively. The obtained results may be due to the higher antioxidant capacity of *B. vulgaris* fruits compared to *B. crataegina.* Sayadi et al. (2021) examined the antimicrobial and antioxidant properties of chitosan, *B. vulgaris* extract, and *Mentha pulegium* essential oil in turkey breast meat packaged with modified atmosphere packaging, and they observed significantly lower TBARS values in the *B. vulgaris*-coated turkey meat compared to untreated and MAP-only samples after the 10th day. The results we obtained are consistent with the literature. Furthermore, *B. vulgaris* extracts can inhibit the production of free radicals with their antioxidant activities. *B. vulgaris* extracts contain essential compounds with antioxidant properties such as berberine, berbamine, palmatine, oxycanthine, malic acid and berberubin. Therefore, *B. vulgaris* extracts can prevent the production of free radicals with their

antioxidant properties (Asadi et al., 2019). In a study conducted by Aliakbarlu and Mohammadi (2015) investigating the effects of sumac and *B. vulgaris* aqueous extracts on microbial growth and chemical changes in lamb leg meat, the TBARS value of all samples was initially determined to be 0.24 mg MDA/kg. However, at the end of storage, TBARS values were found to be 0.44 mg MDA/kg for sumac, 0.76 mg MDA/kg for *B. vulgaris* aqueous extract, and 1.99 mg MDA/kg for the control group, respectively.

Table 5. TBARS (mg MDA/kg) values of marinated meat samples

Time	Control	*B. crataegina*	*B. vulgaris*
3rd h	0.09 ± 0.02^{Aa}	0.61 ± 0.74^{Aa}	0.07 ± 0.03^{Aa}
12th h	0.18 ± 0.01^{Aa}	0.12 ± 0.04^{Aa}	0.17 ± 0.01^{Ba}
24th h	0.63 ± 0.01^{Bb}	0.17 ± 0.04^{Aa}	0.16 ± 0.03^{Ba}
4th day	1.35 ± 0.01^{Cb}	0.22 ± 0.04^{Aa}	0.17 ± 0.04^{Ba}
8th day	1.37 ± 0.06^{Cb}	0.29 ± 0.01^{Aa}	0.18 ± 0.03^{Ba}
12th day	1.54 ± 0.13^{Db}	0.41 ± 0.11^{Aa}	0.19 ± 0.02^{Ba}

The presented values are mean ± SD; a-b and A-D, any two means in the same row having the same letters are not significantly different. SD: standard deviation.

The extract of *B. vulgaris* can enhance the lipid stability of meat samples, thereby extending the shelf life of the meat. This situation indicates that the use of plant extracts in meat products could be a preferred strategy, particularly due to their potential to reduce lipid oxidation.

3.4. Total Aerobic Mesophilic Bacteria (TAMB) and *Enterobacteriaceae*

Meat represents a rich nutrient medium for the development of different types of microorganisms, such as yeast, mold, and bacteria (Aliakbarlu and Mohammadi, 2015). The total aerobic mesophilic bacteria count in meat and meat products is an important parameter that can provide information about product quality, processing and storage conditions, product safety, and shelf life (Atasever, 2011). In the current study, the initial Total Aerobic Mesophilic Bacteria (TAMB) count of the meat used as the material was determined to be 5.93 log CFU/g. The groups had a significant effect ($p<0.01$) on TAMB count at the end of the storage, and a reduction of 3 and 2 units was achieved in the group marinated with *B. vulgaris* compared to the control and *B. crateagina* groups, respectively (Table 6). The study has yielded similar results to the literature. Indeed, in the studies by Aliakbarlu and Mohammadi (2015), a decrease in total viable count compared to the control was observed in samples with added *B. vulgaris*.

Meat is an important food source for various types of bacteria. The *Enterobacteriaceae* family comprises microorganisms frequently encountered in meat spoilage (Bahlinger et al., 2021). Since the *Enterobacteriaceae* family also includes bacteria of fecal origin, the high count of microorganisms from this family is a good indicator of food hygiene and fecal contamination (Takahashi et al., 2017). As seen in Table 7, at the end of the 24th hour and day 12, the *Enterobacteriaceae* count was above 3 log CFU/g in the control group and the group marinated with *B. crateagina*, whereas the *Enterobacteriaceae* count was below the detectable limit (<2 log CFU/g) in the group marinated with *B. vulgaris*.

The total aerobic microorganism count (TAMB) and Enterobacteriaceae counts were found to be lower in meat samples marinated with *B. vulgaris*, indicating potential antimicrobial effects in the meat. Thus, the antimicrobial properties of *B. vulgaris* extract may enhance the microbial integrity of the product by reducing the count of microorganisms in the meat.

Table 6. TAMB count (log CFU/g) of marinated meat samples

Time	Control	*B. crataegina*	*B. vulgaris*
24th h	4.53±0.24[b]	6.09±0.29[a]	3.91±0.55[a]
12th day	8.95±0.07[a]	6.77±0.09[b]	5.74±0.05[c]

The presented values are mean ± SD; a-c, any two means in the same row having the same letters are not significantly different. SD: standard deviation.

Table 7. *Enterobacteriaceae* count (log CFU/g) of marinated meat samples

Time	Control	*B. crataegina*	*B. vulgaris*
24th h	4.36	4.40	<2
12th day	7.41	5.48	<2

The presented values are mean.

3.5. Sensory Analysis

Sensory evaluation is deemed as a crucial instrument in assessing food quality, given that taste, texture, flavor, and aroma play a pivotal role in food preferences and dietary habits. (Djekic et al., 2021). Sensory analysis was widely applied to fresh and processed meat (Moerlein et al., 2019).

Using different fruit extracts *(B. vulgaris* and *B. crataegina*) in the marinating solution did not cause a statistical difference between the groups ($p>0.01$) (Table 8). According to the sensory analysis results, meat samples marinated with *B. vulgaris* extract have similar taste, aroma, texture, and overall acceptability values compared to the control group. This suggests that the use of Berberis extracts does not negatively impact the flavor, texture, and overall sensory quality of the meat and may even enhance these attributes under certain circumstances. These positive sensory outcomes indicate that the use of Berberis extracts in meat marination is deemed acceptable by consumers and could be considered as an alternative to traditional marination methods. This provides a potential solution for both improving meat quality and meeting the preferences of consumers who prefer natural antioxidant use.

Table 8. Sensory analysis of marinated meat samples

	Control	*B. crataegina*	*B. vulgaris*
Color	6.71±0.95[a]	7.43±2.15[a]	6.86±1.07[a]
Texture	6.57±1.72[a]	5.57±1.72[a]	6.71±2.14[a]
Smell	6.86±1.07[a]	6.14±1.86[a]	6.00±2.08[a]
Taste	6.00±2.31[a]	6.14±1.86[a]	6.00±2.08[a]
General Acceptability	6.71±0.95[a]	6.29±1.60[a]	7.14±1.46[a]

The presented values are mean ± SD; a-d, any two means in the same row having the same letters are not significantly different. SD: standard deviation.

4. Conclusions

In conclusion, the evaluation of the impact of *B. vulgaris* and *B. crataegina* fruit extracts on meat quality presents promising results. Both extracts exhibit significant antioxidant activity, along with variations observed in phenolic content. The marination process influences the pH and lipid oxidation of the meat during storage. Despite no significant sensory differences, high overall acceptance scores for meat groups marinated with *B. vulgaris* emphasize its potential as a positive option to enhance meat quality.

The study suggests that *B. vulgaris* and *B. crataegina* fruit extracts could be employed as natural additives in the meat industry. Further research is needed to delve into the specific mechanisms underlying the observed effects and their long-term implications on meat products.

Utilizing these plant extracts as functional ingredients aligns with the increasing interest in natural and sustainable approaches in food processing. This research contributes to the expanding knowledge base on the application of plant extracts to enhance meat quality, opening doors for future discoveries and innovations in the field.

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Author Contributions

KCT: Laboratory experiments, Validation, Investigation, Resources, Writing-original draft, Project administration ÖÇ: Laboratory experiments, Writing-review. KF: Laboratory experiments, Writing-review.

Conflict of Interest

All the authors declare no conflict of interest.

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