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Effects of Marination Process using Okra (*Abelmoschus esculentus* L.) Powder on Physicochemical and Textural Properties of Beef Meat

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Abstract

The purpose of this study was to investigate the effect of the marination process, using boiled and unboiled dry okra powder, on the physicochemical and textural properties of beef round meat obtained from beef carcass. A general decrease in pH values was observed, with the lowest value detected in BO1. The differences in the *L**, *a**, and *b** values of the samples were statistically significant ($P < 0.05$). Water-holding capacity (WHC) was also markedly affected. The highest WHC was observed in O2. Cooking loss decreased in the okra-treated groups compared to C1, and the okra powder solutions yielded cooking loss values ranging from 21.44% to 37.72%. The cohesiveness, springiness, and resilience values of the samples were not statistically significant ($P > 0.05$). The highest hardness value was recorded in O2 (320.34), whereas the lowest was observed in BO1 (181.9).

Keywords: Beef meat marination, okra powder, meat quality, physicochemical properties, texture profile

1. Introduction

The marination process is a simple meat processing technique that has long been widely used both in home cooking and in the meat industry, often involving the incorporation of various additives [1]. In general, a wide range of marinating ingredients are available on the market, including salts, phosphates, acids, sugars, flavorings, and antioxidants [2]. Moreover, marination enables the addition of spices to develop new flavors or to enhance existing ones. Marination solutions containing sugars, spices, oils, or acids [such as vinegar, fruit juices, or wine] are commonly employed to extend shelf life and to improve the crispness, juiciness, flavor, and aroma of red meat, poultry, and seafood [3]. In addition to increasing the yield of raw meat, marination also contributes to a more tender and juicy texture, reduces cooking losses, enhances water-holding capacity, and improves the color and flavor of the meat—these being among its most significant positive effects [4, 5].

Today, beef has become a high-value gastronomic product, particularly due to its growing popularity in fine dining restaurants [1, 6]. The meat industry has seized significant marketing opportunities in response to increasing consumer demand for marinated meats and ready-to-cook products that offer convenience [7]. However, consumers are increasingly seeking “clean-label” products, including meat and meat-based items, which are produced without the use of preservatives or synthetic additives [5].

Herbs and spices such as onion, garlic, rosemary, black pepper, thyme, turmeric, lemongrass, coriander, cinnamon, parsley, mustard, and lemon juice are frequently used in traditional marination processes [6]. Okra (*Abelmoschus esculentus* L.), a member of the Malvaceae family, is a fibrous dietary vegetable that is highly rich in mucilage and is also known for its antioxidant activity [8, 9].

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Previous studies have shown that okra-based additives can cause significant changes in texture profile analyses [10-12]. The addition of okra powder or mucilage at increasing concentrations has been reported to improve the sensory and textural properties of various products such as bread, yogurt, and snacks. As a natural hydrocolloid, okra mucilage plays an important role in enhancing moisture content due to its high water-binding and gel-forming abilities, thereby improving water-holding capacity and reducing cooking losses [13-15].

An increase in the surface area of the plant material (such as through chopping) and the application of heat directly influence the characteristic structure of mucilage [16]. The cooking process alters the enzymatic activity and the soluble polysaccharide composition of okra. Pectin derived from okra has attracted attention due to its unique fine structure, high surface activity, and strong biological functionalities [17]. Accordingly, in this study, the effects of marination solutions prepared from blanched and unblanched okra on the physicochemical properties of beef will be comparatively evaluated.

2. Materials and method

2.1. Materials

In this study, okra belonging to Sultani variety was used and obtained from a local market in Konya, Turkiye. Beef meat purchased from a contracted butcher in Konya was quickly taken to the relevant laboratory and stored in the cold (+4 ^{o}C).

2.2. Sample preparation

Okra powders were prepared in two different ways. First group was boiled in 90 °C 5 minutes in pure water. The second group was not boiled. Then both groups were dried for 3 days at room temperature. Solutions were prepared in the ratios of 1:20, 1:40, 1:80 (okra: pure water) using dried and ground okra powders. Okra mucilage exhibits a gel-like structure at high concentrations; therefore, in order to avoid hindering diffusion and functional effects during marination, the proportion of okra powder in the solution was planned not to exceed 5% (w/v). The beef meat, average 25-30 g was divided into pieces, placed in 200 ml okra solution. As control, only the sample with pure water added and samples containing no marination solution were used.

Table 1 Descriptions of the groups used in the marinade solution

Group	Treatment description	Ratio (w/v)
C1	Water-marinated control	-
C2	Non-marinated control	-
O1	Unboiled okra powder	1:20
O2	Unboiled okra powder	1:40
O3	Unboiled okra powder	1:80
BO1	Boiled okra powder	1:20
BO2	Boiled okra powder	1:40
BO3	Boiled okra powder	1:80

2.3. Color and pH

Color measurements of beef meat samples (*L**, *a** and *b** values) were carried out using a Chrometer (CR-400 model, Konica Minolta, Osaka, Japan) with D65 illumination, Diffuse / O mode with 2° observer and 8 mm illumination range. *L** (brightness), *a** (redness, +60, red; -60, green) and *b** (yellowness, +60, yellow; -60, blue) colour coordinates has been identified according to colour coordinates of CIE *L**, *a**, *b** colour coordinate system [18]. Measurements were taken directly from three different areas of the samples placed on a white background.

The pH value of the beef samples was measured using a dimple pH meter (Testo 205, Germany) calibrated with buffer solutions (pH 4.0 and pH 7.0) at room temperature before analysis [19].

2.4. Water holding capacity [WHC]

Two g of homogenized beef meat samples were weighed on filter paper (M) and placed in centrifuge tubes. After centrifugation at 5000 rpm for 10 min, the wet filter paper was weighed (W1). The wet filter paper was dried at 60 °C to a constant weight (W2). Water holding capacity was calculated as the amount of sample remaining after centrifugation [20].

$$WHC\% = [(W1-W2)/M] \times 100$$

2.5. Cooking losses [CL]

20 g of beef meat sample (A) was weighed into tared polyethylene bags (B). After cooking in a water bath at 80 °C for 20 minutes, the liquid phase in the bags was removed and the remaining solid phase was weighed (C) [21].

$$CL\% = [A-(C-B)]/A \times 100$$

2.6. Texture profile analysis

Each sample was shaped into 35-40 mm diameter and 10-12 mm height patties with a weight of 40-50

g. The textural profile [hardness, cohesiveness, chewiness, springiness and adhesiveness] analysis of uncooked beef was determined by using a texture analyser (Stable Micro Systems TA.HD Plus, TA, Stable Microsystems Godalming, Surrey, UK). The instrument was programmed for a 100 kg load cell and cross head speed of 100 mm/ minute, probe diameter 36 mm [22, 23].

2.7. Statistical analyses

The obtained data were analyzed using MINITAB version 17.0. A generalized linear mixed model was applied to perform analysis of variance (ANOVA) for all experimental results. Approximate F-ratio tests were used for each fixed effect, and statistical significance was determined at the 0.05 level. Differences among group means were evaluated using Tukey's Multiple Comparison Test at the 5% significance level [24].

3. Results and Discussion

3.1. pH results

The effect of the treatment process with okra solution on pH is presented in Figure 1. Treatment with okra significantly reduced the pH value of the meat samples ($P < 0.05$). The lowest pH value was recorded in BO1. The pH of the samples treated with okra was relatively lower compared to the control groups.

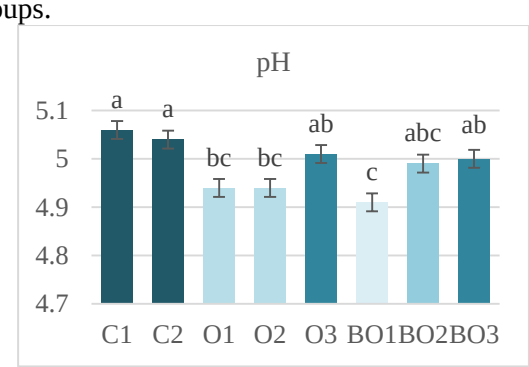

Figure 1. pH values of beef meats treated with different concentrations of okra solution
Values are means of triplicate samples (±SE).
a–c Means within columns with different superscript letters are significantly different [$P < 0.05$].
C1: Water + beef, C2: Beef, O: Okra solution + beef, BO: Boiled okra solution + beef

Similar results have been reported in studies using different marination solutions. Istrati *et al.* [2011] [25] marinated fresh beef slices in solutions containing dry red wine, lime-tree honey, salt, thyme, marjoram, garlic, and horseradish, and observed a decrease in pH values during the early days of storage after marination [4.90 to 4.94]. Ardicli *et. al.* [2024] [7] also noted that the pH of the non-marinated control group [5.85] was higher than that of beef marinated with milk, lemon juice, and olive oil–garlic solutions [5.37, 5.82, and 5.72, respectively].

3.2.Colour results

The *L** (lightness), *a** (redness–greenness), and *b** (yellowness–blueness) values of the raw and cooked beef samples are presented in Table 2. The differences in *L**, *a**, and *b** values among the uncooked samples were found to be statistically significant ($P < 0.05$). The lowest *L** value among the raw samples was observed in C2. Samples treated with solutions containing okra powder at a 1:40 ratio exhibited lower *L** values than those treated with other concentrations. Overall, treatment with okra yielded results similar to water treatment in terms of *L** and *a** values in the raw samples. Increases in *L** values have been attributed to low pH, swelling of muscle proteins, and changes in light reflectance due to ionic strength [26, 27]. The *L** values of all okra-marinated samples were lower than those of the control groups after cooking ($P < 0.05$). Water loss during cooking influences the *L** value, and as water is lost, the meat becomes less opaque [28].

When the *a** values of the uncooked samples were examined, C2 exhibited the highest value (17.9), while O2 showed the lowest (8.7). Marination has generally been reported to reduce the redness of beef [7, 28]. Several studies have demonstrated that myoglobin denaturation leads to decreased *a** values (redness) and increased *b** values (yellowness) [29, 30]. Among the raw samples, the highest *b** value was recorded in C2, whereas the lowest values were observed in O1 and BO1. Zhang *et al.* (2020) [31] suggested that changes in *a** and *b** values are associated with the proportions of deoxymyoglobin (Mb], oxymyoglobin (MbO_2), and metmyoglobin (MetMb). Accordingly, an increase in Mb significantly decreases *b**, an increase in MbO_2 significantly increases both *a** and *b**, and an increase in MetMb results in a significant reduction in *a** value.

For the cooked samples, the highest *a** value was observed in BO3. Increases in *a** values in meat are expected to be associated with elevated pigment concentrations, which alter the relationship between the relative content of myoglobin and the effects of achromatic absorption on meat color [31]. The *b** values of the cooked samples ranged from 9.7 to 11.6 and were very similar across treatments ($P > 0.05$)

Table 2 *L**, *a**, *b** values of beef meats treated with different concentrations of okra solution

	Treatment	*L**	*a**	*b**
Raw	C1	55.5±0.5^{a}	9.2±0.7^{b}	6.6±0.7^{b}
	C2	36.0±0.7^{d}	17.9±0.8^{a}	10.1±0.7^{a}
	O1	53.0±0.4^{b}	9.4±0.1^{b}	4.9±0.1^{c}
	O2	55.3±0.7^{a}	8.7±0.4^{b}	9.0±0.0^{a}
	O3	49.1±0.9^{c}	9.4±0.2^{b}	8.8±0.2^{a}
	BO1	54.2±0.2^{ab}	10.1±0.3^{b}	4.7±0.3^{c}
	BO2	53.6±0.8^{b}	9.8±0.3^{b}	6.9±0.0^{b}
	BO3	49.9±0.4^{c}	10.0±0.5^{b}	5.5±0.3^{bc}
Cooked	C1	43.7±0.1^{b}	9.0±0.6^{b}	9.7±0.9^{a}
	C2	46.7±0.7^{a}	9.9±0.2^{ab}	10.9±0.4^{a}
	O1	40.4±0.6^{c}	9.8±0.5^{ab}	10.9±0.2^{a}
	O2	38.8±0.9^{de}	8.8±0.8^{b}	10.2±0.2^{a}
	O3	37.4±0.4^{e}	9.8±0.5^{ab}	9.7±0.6^{a}
	BO1	40.0±0.8^{cd}	9.4±0.1^{b}	10.9±0.7^{a}
	BO2	40.6±0.1^{c}	9.3±0.5^{b}	10.7±0.1^{a}
	BO3	38.6±0.3^{de}	12.3±0.8^{a}	11.6±0.7^{a}

Values are means of triplicate samples (±SE).
a–e Means within columns with different superscript letters are significantly different ($P < 0.05$).
C1: Water + beef, C2: Beef, O: Okra solution + beef, BO: Boiled okra solution + beef

3.3. Water holding capacity (WHC)

Water holding capacity (WHC) values are presented in Table 3. Except for O2, all samples exhibited lower water holding capacity compared to the control groups ($P < 0.05$). In particular, the samples treated with boiled okra showed lower WHC values than those treated with unboiled okra. While the lowest WHC was observed in BO3 (71.15%), the highest was recorded in O2 (80.25%).

Several studies have also reported lower WHC values in marinated meat samples compared to controls [32, 33].

Physiological and anatomical factors, as well as slaughtering and processing conditions, may influence WHC [33]. Generally, when the pH value falls below the isoelectric point, an increase in WHC is expected. As the pH moves away from the isoelectric point, marination solutions penetrate the myofibrils, thereby increasing water retention [30]. In the present study, despite the low pH values of O1, O2, BO1, and BO2, only O2 exhibited a higher WHC than the control groups. This may be related to the presence of free water, which can be easily lost during cooking. Moreover, sarcoplasmic proteins may precipitate onto myofibrillar proteins, leading to an overall reduction in reactive protein groups capable of binding water, thereby decreasing WHC [33].

Table 3 WHC and CL values of beef meats treated with different concentrations of okra solution

Treatment	WHC (%)	CL (%)
C1	76.00±0.00^{bc}	38.85±0.06^{a}
C2	77.25±0.35^{bc}	18.95±0.17^{g}
O1	73.25±0.41^{d}	33.87±0.47^{c}
O2	80.25±0.12^{a}	37.72±0.43^{a}
O3	74.75±0.41^{c}	28.35±0.49^{e}
BO1	69.50±0.35^{f}	21.44±0.11^{f}
BO2	71.50±0.71^{e}	29.96±0.58^{d}
BO3	71.15±0.05^{e}	35.52±0.45^{b}

Values are means of triplicate samples (±SE).
a–g Means within columns with different superscript letters are significantly different ($P < 0.05$).
C1: Water + beef, C2: Beef, O: Okra solution + beef, BO: Boiled okra solution + beef

3.4. Cooking losses

The results for cooking loss are presented in Table 2. The differences among the groups were found to be statistically significant ($P < 0.05$). Treatment with okra reduced the cooking loss compared to C1. The

lowest cooking loss was observed in C2. The cooking loss values of the samples marinated with okra powder solutions ranged between 21.44% and 37.72%.

In contrast to the generally lower cooking losses reported for marinated samples in the literature, Barbanti and Pasquini (2005) [34] observed relatively high cooking losses (38.03–44.74 g/100 g). The authors attributed this finding to the absence of polyphosphate in the marination solution. Their study also indicated that cooking losses were more closely related to cooking time than to cooking temperature.

Jinap *et al.* (2015) [35] reported that the percentage of weight loss in satay samples treated with local spices differed significantly ($P < 0.05$), which they associated with water loss during grilling. Similarly, Gamage *et al.* (2017) [36] found that marination method and holding time had statistically significant effects on cooking loss (CL).

3.5. Texture profile analysis

Table 4 presents the textural properties of beef treated with different concentrations of okra solutions. According to the analysis results, no statistically significant differences were observed in the cohesiveness, springiness, or resilience values ($P > 0.05$). The highest hardness value was recorded in O2. BO2 exhibited higher hardness values than BO1 and BO3. In general, samples treated with boiled okra were more effective in reducing meat hardness than those treated with unboiled okra. The lowest hardness values were observed in BO1 and BO3. Similar trends were also observed for gumminess and chewiness. Xu *et al.* (2019) [14] reported that the addition of okra mucilage increased the hardness and elasticity of yogurt. Likewise, Noshad *et al.* (2021) [37] observed that the hardness values of buffalo meat coated with Plantago major seed mucilage were higher than those of the control group throughout the storage period.

Table 4. Texture analysis parameters of beef meats treated with different concentrations of okra solution

Treatment	Hardness (N)	Gumminess (N)	Cohesiveness	Chewiness (N*mm)	Springiness	Resilience
C1	215.42 ± 3,80^{cd}	143.42 ± 5.82^{cd}	0.666±0.01^{a}	109.96±7.35b^{cde}	0.766±0.02^{a}	0.236±0.03^{a}
C2	262.38 ± 9.59^{abc}	154.59 ± 10.39^{bc}	0.589±0.02^{a}	112.26±11.52^{bcd}	0.725±0.03^{a}	0.199±0.04^{a}
O1	286.10 ± 0,96^{ab}	180.22±4.52^{a}b	0.630±0.02^{a}	133.24±5.14^{ab}	0.740±0.05^{a}	0.236±0.00^{a}
O2	320.34 ± 13.78^{a}	193.5±4.35^{ab}	0.605±0.04^{a}	147.5±17.9 ^{a}	0.761±0.08^{a}	0.208±0.01^{a}
O3	225.92 ± 8.92^{cd}	141.54±4.82^{cd}	0.627±0.05^{a}	94.96±5.16^{cde}	0.672±0.06^{a}	0.254±0.03^{a}
BO1	187.73 ± 5.90^{d}	121.5±3.58^{de}	0.648±0.03^{a}	82.05±2.47^{e}	0.676±0.03^{a}	0.244±0.01^{a}
BO2	238.95 ± 3.30^{bc}	144.58±0.91^{c}	0.605±0.01^{a}	111.48±8.4 ^{bc}	0.771±0.06^{a}	0.224±0.02^{a}
BO3	181.90 ± 11.90^{d}	113.66±16.65^{e}	0.630±0.04^{a}	87.84±2.32^{de}	0.778±0.06^{a}	0.238±0.01^{a}

Values are means of triplicate samples (±SE).

a–e Means within columns with different superscript letters are significantly different ($P < 0.05$).

C1: Water + beef, C2: Beef, O: Okra solution + beef, BO: Boiled okra solution + beef

Okra mucilage is easily extracted in aqueous environments due to its highly soluble polysaccharides, and the extraction method directly influences its physicochemical properties [38]. Therefore, it is assumed that the mucilage obtained at a 1:40 ratio reached an optimal balance of polysaccharide penetration and viscosity, forming a film-like layer on the meat surface. Dissolved polysaccharides have been reported to interact with surrounding water clusters through hydrogen bonding, creating a relatively immobilized structure [11, 39].

In addition to having a high hardness value, O2 also exhibited the highest water-holding capacity (80.25%). This may be related to the structural modifications and rheological behavior of okra pectin [40]. Moreover, pectin has been shown to interact effectively with meat proteins through hydrogen bonding and free binding energy [41]. Pectin–protein interactions may involve a highly complex binding mechanism composed of pH-sensitive electrostatic attractions, hydrogen bonding, hydrophobic interactions, and multiple non-covalent interactions [42]. Therefore, the parallel trend observed between WHC and hardness in the present study may be associated with the stabilizing effect of these interactions on protein structure, allowing water to remain more tightly bound within the matrix.

4. Conclusion

In the present study, the effects of boiled and

unboiled okra solutions on the textural properties and some quality parameters of beef were investigated. The results demonstrated that marination with okra solutions, particularly at a 1:40 concentration, led to significant alterations in the physicochemical and textural properties of beef. Although the lowest pH value was observed in BO1, okra treatment generally resulted in a reduction in pH. The higher L^* values prior to cooking were associated with lower pH, whereas the decreased L^* values after cooking were interpreted as a consequence of water loss and the resulting reduction in opacity. The observed changes in redness and yellowness values were largely attributed to protein denaturation and/or pigment transformations. Marination typically reduces the redness of meat. The highest a^* and b^* values were recorded in C2.

Except for O2, all okra-treated samples exhibited lower water-holding capacity (WHC) compared to the control. Although WHC is generally expected to increase when the pH falls below the isoelectric point, our findings demonstrated the opposite trend. This may be attributed to a reduction in the reactive protein groups responsible for water binding. Notably, samples treated with boiled okra exhibited lower WHC than those treated with unboiled okra. Cooking loss decreased in the okra-treated groups compared with C1. Okra treatment increased the hardness of the samples, and the findings were interpreted in the context of the complex interactions between pectin and proteins.

Marination with okra powders significantly influences key quality parameters of red meat, including color, water-holding capacity, and texture [hardness]. Naturally, the physiological and anatomical characteristics of the meat, as well as slaughtering and processing conditions, play a critical role in these outcomes. A comprehensive understanding of these interactions will support the broader adoption of clean-label and natural plant-based ingredients, thereby contributing to enhanced sustainability in meat processing. Further research using standardized okra concentrations and sensory evaluation is needed to optimize marination performance and consumer acceptance.

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Availability of data and material: The data have been reviewed depending on the literature.

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