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[1]Department of Animal Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

***Corresponding Author:**

MAK Azad
E-mail: azad_animalscience@bau.edu.bd

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Research Article

Physico-chemical properties and shelf life of meatballs available in the local market of Bangladesh

J Ferdushe[1], MM Mahbub[1], JF Juthi[1], SJ Badhan[1] HM Murshed[1], MAK Azad[1*]

Abstract

The present study assesses the physicochemical characteristics and shelf life of meatballs sourced from four distinct brands present in the local market of Bangladesh. The study focused on identifying key characteristics that affect the quality of meatballs and the preferences of consumers. The findings from sensory evaluation, proximate analysis, and CIE (L^*, a^*, b^*) color analysis indicate that Brand A consistently excelled compared to the other brands in flavor, tenderness, and overall acceptability, with statistically significant differences ($p < 0.05$) observed across all assessed attributes. In the proximate analysis, Brand A exhibited the highest levels of crude protein (45.03%) and ether extract (29.35%), thereby improving its nutritional quality. The physico-chemical analysis revealed that Brand A exhibited exceptional moisture retention, as indicated by its low cooking loss (2.35%) and drip loss (0.95%), in addition to optimal shear force and water-holding capacity. The assessment of color using CIE (L^*, a^*, b^*) revealed that Brand A's product was the most visually appealing, exhibiting greater brightness ($L^* = 71.64$) and yellowness ($b^* = 34.41$). Conversely, Brands B, C, and D demonstrated reduced tenderness, increased cooking loss, and less appealing color attributes. The findings indicate that Brand A stands out as the superior meatball product, presenting an optimal blend of sensory attributes, nutritional benefits, and favorable physicochemical characteristics. This analysis highlights the significance of these elements in influencing consumer choices and market dynamics, suggesting ways to improve meatball quality and shelf life.

Introduction

Meatballs are a popular food item in Bangladesh because of their rich flavor, ease of preparation, and nutritional value. Usually composed of minced meats like chicken, beef, or mutton, meatballs are sometimes seasoned with a range of regional spices to provide unique flavors. Often eaten as appetizers, snacks, or as a component of main courses, these flavorful meatballs are an essential aspect of Bangladeshi cuisine. Due to factors like rising urbanization, shifting lifestyles, and rising demand for ready-to-eat food products, meatball consumption has increased dramatically over time (Amin et al., 2024). In Bangladesh, the meatball market provides a rich variety, featuring both freshly prepared and pre-packaged options, available in a variety of sizes, flavors, and textures to meet the diverse tastes of consumers (Akter et al., 2022; Ali et al., 2022; Hossan et al., 2024; Islam et al., 2018; Khatun et al., 2022; Mostafa et al., 2025; Ozturk & Hamaker, 2023). The physicochemical properties of meatballs are critical for determining their quality, texture, sensory appeal, and shelf life. Key parameters such as pH, water-holding capacity, drip loss, shear force, cooking loss, and water activity directly influence the product's stability, texture, and flavor (Abdul et al., 2025, Azad et al., 2021 and 2022). The pH level of meatballs is crucial for their ability to retain moisture and maintain microbial stability. A balanced pH plays a crucial role in preventing spoilage and improving texture, while deviations towards low or high pH can result in moisture loss and undesirable texture (Laksanawati et al., 2024). Another significant factor that affects the tenderness and juiciness of meatballs is their Water-holding capacity. Lower water-holding capacity can result in dried and tough meatballs, while higher water retention leads to a juicier and more tender product (Cheng & Sun, 2008). In addition, the retention of moisture during cooking and the tenderness of meatballs are critical parameters that influence overall consumer satisfaction, as well as shear force and cooking loss (Hussain et al., 2024). The shelf life of meatballs is a critical factor in determining their safety and quality over time, in addition to their physicochemical properties. The shelf life is influenced by the combination of constituents, processing methods, and storage conditions. Meatballs with an extended shelf life are more stable and less susceptible to microbial contamination, which minimizes the risk of decomposition and ensures their safety for consumption over time (Das et al., 2022; Meng et al., 2022). Research indicates that including natural preservatives, like lemon extract, might markedly extend the shelf life of meatballs by preventing microbial proliferation and oxidative rancidity (Disha et al., 2021; Mahmud et al., 2024; Sagar et al., 2024; Shohiduzjaman et al., 2024). Furthermore, appropriate management and storage methods, such as refrigeration or freezing, are essential for maintaining the quality and safety of meatballs. In Bangladesh, where meatballs hold a significant place in the culinary context, it is essential to comprehend their physicochemical characteristics and shelf life to maintain product quality and safety. While meatballs enjoy widespread popularity, there exists a fat content, seasoning, and processing methods can significantly influence product quality, safety, and consumer appeal. This study aims to fill this gap by examining the physicochemical characteristics of meatballs found in local markets of Bangladesh, concentrating on factors such as pH, water-holding capacity, drip loss, shear force, and water activity. Furthermore, the investigation will assess the shelf- life of these meatballs to comprehend how these characteristics affect their microbial stability and overall freshness.

The findings of this study will help producers, wholesalers, and consumers make wise decisions by offering insightful information about the safety and quality of meatballs in Bangladeshi local markets. The results can help producers enhance food safety regulations, quality control procedures, and product formulas. Meatball manufacturers will be able to satisfy the rising demand for premium, secure, and long-lasting meat products by having a thorough understanding of consumer preferences, including the desire for products with improved texture, flavor, and shelf life. This study can help enhance public health and overall food safety by informing regulatory rules and quality requirements for meatball production in Bangladesh for policymakers and food safety agencies.

Materials and methods

Equipment and Instrument Preparation

The equipment required included a plastic pot, refrigerator, crucible, HANNA meat pH meter, digital food grade thermometer, colorimeter, smart water activity meter, shear force machine, water bath, petri dishes, knife, chopping board, water, and tissue paper. Before the experimental activities started, all essential instruments were cleansed with hot water and detergent powder, and subsequently autoclaved and dried appropriately.

Sample collection and preparation

4 different brands of meatballs were collected from the local market of Mymensingh. Then the samples were immediately transferred to the Meat Research Unit under the Department of Animal Science at Bangladesh Agricultural University, Mymensingh.

Sensory Evaluation

A trained 3-member panel used a 5-point balanced semantic scale (weak to strong) to evaluate each meatball sample's color, flavor, tenderness, juiciness, and overall acceptability. Panelists—department personnel and students were trained according to American Meat Science Association (AMSA, 1995) guidelines. Sensory evaluations were conducted in controlled booths with lighting, temperature, and humidity. Before assessing chicken meatballs pre- and post-cooking, panelists completed scale orientation sessions. Sensory scores were 1 (poor) to 5 (excellent) on a 5-point scale. Samples were served on petri dishes.

Proximate composition

The proximate components of meatball samples were determined in accordance with the AOAC (2005). All estimates of dry matter content were determined using a micro-oven at 105°C for 24 h, while ash content was assessed using a muffle furnace at 550°C for 5 h (AOAC, 2005). By subtracting the ash percentage from 100, the OM content of all samples was calculated. The CP content of all samples was determined using the Kjeldahl technique, whereas the CF percent was measured by digesting samples in 1.25% H_2SO_4 and then 1.25% NaOH. The Soxhlet device was used to determine the EE% in all samples.

Physicochemical properties

pH

The pH of the meatball samples was determined by the direct method using a pre-calibrated portable pH meter (HI98163, HANNA Instruments, and Australia). The tip of the above pH meter was inserted into the meat sample until a stable reading was obtained.

Cooking loss

Chicken meatball cooking loss was calculated using (Achudan et al., 2024) method. The meatball was cooked for six minutes in 80–90°C water. Next, the meatball was fried for 2 minutes at 175–185 °C in oil. To compute chicken meatball cooking loss (%), the weight difference between the samples before and after cooking was used.

The results were expressed as the cooking loss percentages using the following formula:

$$Cooking\ loss\ (\%) = \frac{weight\ before\ cooking - weight\ after\ cooking}{weight\ before\ cooking} \times 100$$

Drip loss

Samples were stored in a refrigerator at 4°C for 24 hours to measure drip loss. Meatball samples were suspended in tightly sealed plastic bags filled with air and kept at 4°C for 24 (Honikel, 1998) Drip loss was calculated as a percentage of the weight loss after suspension. Drip loss was estimated by using the following calculation:

$$Drip\ loss\ (\%) = \frac{initial\ weight\ of\ the\ sample\ - final\ weight\ of\ the\ sample}{initial\ weight\ of\ the\ sample} \times 100$$

Water holding capacity

The water-holding capacity of the meatball sample was measured in terms of dry matter content using a modified centrifugation method, as described by Honikel (1998). Briefly, about 1g of meatball sample was placed into 2 ml Eppendorf tubes and then centrifuged at 10,000 rpm for 10 min at 4°C. After centrifugation, the tubes were decanted and reweighed to obtain the post-centrifugation weight. The samples were then dried in a hot air oven at 105°C for 24 hours until a constant weight was achieved to determine dry matter content. Water-holding capacity was calculated as the remaining moisture in the meat sample on the basis of the original sample.

The water holding capacity was calculated using the following formula:

$$WHC\ (\%) = \frac{weight\ after\ centrifugation - dry\ weight\ of\ the\ sample}{initial\ weight\ of\ the\ sample} \times 100$$

Shear force

Shear force values were measured according to the method described by Honikel (1998) with little modification. The samples used for cooking loss were collected and used to measure the tenderness of the meatball. Sample preparation was done following the technique previously described by Honikel (1998). Thereafter, 0.5 cm cores were taken from each sample and sheared once on a Warner-Bratzler shear machine (G-R Elec. Mfg. Co, Manhattan, KS) to determine the mechanical force (N) required to shear the samples. An average shear force was calculated and recorded for each sample.

Color

The color of the meatball was evaluated on the freshly cut surface using Instrumental color measurements in the CIE L*, a*, b* system, which was carried out using an electronic 3nh NR20XE colorimeter (Shenzhen, China).

Water activity

A calibrated smart water activity meter using NaCl and MgCl salt solutions was employed to evaluate the water activity (a_w) of the meatball. Following the homogenization of the meatball sample, it was transferred to a sterile petri dish for measurement. In order to mitigate temperature variations, the apparatus achieved stabilization and presented the a_w value upon reaching equilibrium. Subsequently, the a_w values were recorded.

Statistical Analysis

Data were analyzed using Minitab 17. A One-Way ANOVA was performed to assess significant differences between the brands. Post-hoc comparisons were conducted using the Tukey test at ($p < 0.05$**)** to identify pairwise differences. Results are presented as mean ± standard error (SE).

Results and discussion

Sensory Evaluation

Color

Table 1 presents the color scores of several brands, with a range from 4.19 to 4.89 among treatments ($p<0.05$). Brand A achieved the highest color score among the four brands, indicating the most favored hue. Conversely, Brand D demonstrated the lowest score, indicating the least favored hue. These data indicate customer preferences about color appeal, a crucial element in the sensory evaluation of meat products. Islam et al. (2018) reported similar findings, demonstrating that meatballs using 15% wheat flour achieved the greatest color score among the different interventions.

Flavor

Table 1 shows the flavor scores of several brands. The flavor scores for the meatball brands ranged from 4.11 to 4.30, with statistically significant differences ($p<0.05$) observed. Brand B (4.30) scored the highest preference, but Brand D (4.11) scored the lowest rating. Flavor is a crucial factor in consumer preference for meat products, as even little variations can affect overall acceptability. Brand B's higher score signifies a more attractive flavor profile, aligning with studies that show ingredients and storage conditions significantly influence flavor stability (Hossan et al., 2024).

Juiciness

The juiciness scores of different brands are presented in Table 1. Juiciness scores varied significantly among brands, ranging from 4.26 to 4.41 ($p < 0.05$). Brand A scored 4.41, followed by Brand C (4.39), and Brand D (4.26) was the least juicy. Juiciness is intimately linked to fat content and water-holding capacity, affecting mouthfeel and sensory appeal (Huff-Lonergan & Lonergan, 2005). The higher score of Brand A signifies better moisture preservation and an ideal fat-to-lean ratio, whereas Brand D's lower score may indicate reduced fat or higher cooking loss. Similar findings by Tornberg (2005) showed that balanced moisture and fat levels improve meat juiciness and consumer satisfaction.

Overall Acceptability

The meatball brands' overall acceptability scores varied from 4.17 to 4.40 ($p < 0.05$), indicating significant variances. Brand A scored 4.40, followed by B and C, and Brand D (4.17) was the least preferred. Overall acceptability measures color, flavor, texture, and juiciness to assess product quality and consumer satisfaction. Brand A's higher ratings for color and juiciness, which influence consumer liking, explain its higher score. Brand D's lower score shows sensory weakness across numerous aspects. (Serdaroğlu, 2006) found that juiciness and flavor were key to meatball acceptability, and (Grasso et al., 2019) found that "juicy" and "moist-looking" characteristics influenced consumer liking in hybrid beef meatballs.

Table 1: Sensory evaluation of different brands of meatballs available in the market

Parameters	Brand A	Brand B	Brand C	Brand D	P value	Level of significance
Color	4.89^a±0.02	4.87^b±0.02	4.87^b±0.03	4.19^c±0.83	0.000	**
Flavor	4.27^c±0.22	4.30^a±0.21	4.28^b±0.22	4.11^d±0.54	0.000	**
Juiciness	4.41^a±0.12	4.35^c±0.14	4.39^b±0.12	4.26^d±0.54	0.000	**
Overall acceptability	4.40^a±0.08	4.34^b±0.10	4.33^b±0.11	4.17^c±0.73	0.000	**

[a-d] Mean ± (SE) within a row showing different superscripts are significantly different (P<0.05)

Physicochemical properties

pH

Table 2 shows that meatballs from different brands had pH values from 6.39 to 6.63. Brand B had the highest pH, Brand A the lowest. Meatball texture, flavor, color stability, and microbiological shelf life depend on pH. Acidic additives and preservatives improve flavor and limit microbial growth at lower pH values (Andrés-Bello et al., 2013). Lower pH promotes protein denaturation and reduces water-holding capacity, making the texture harder. Cho et al. (2021) showed that pH greatly impacts protein solubility and binding in processed beef products, affecting sensory quality. Brand A may have higher sensory acceptability than other brands due to its lower pH and tougher texture.

Water holding capacity

The water-holding capacity (WHC) of meatballs from various brands, shown in Table 2, varied from 98.28% to 99.79%. Marked variations ($p < 0.05$) were observed among the brands, with Brand A demonstrating the maximum water holding capacity (WHC). The water-holding capacity (WHC) is a crucial factor influencing texture, juiciness, and yield in meat products. A higher water-holding capacity (WHC) is typically linked to juicier, more tender meatballs, while a lower WHC may result in increased moisture loss during cooking, adversely affecting texture and sensory quality. The water-holding capacity of meatball compositions is affected by variables including meat type, fat level, and the incorporation of binders or fillers. Furthermore, pH is crucial decreased pH can facilitate protein denaturation, thereby diminishing water retention(Huff-Lonergan & Lonergan, 2005; Warner, 2017). Brand A, being the highest water-holding capacity, signifies a superior formulation that preserves moisture throughout cooking, hence improving texture and product quality. Conversely, the other brands exhibited negligible variation in water holding capacity, indicating suboptimal moisture retention. Consequently, Brand A seems to be the most desirable owing to its enhanced water-holding capacity.

Drip Loss

As shown in Table 2, meatball drip loss (%) varied between 0.95% in Brand A and 1.86% in Brand D, with significant variations ($p < 0.05$). Brand A had the lowest drip loss, indicating better cooking moisture retention. Meat product quality and water-holding capacity (WHC) depend on drip loss. Lower drip loss is associated with greater texture, juiciness, and sensory qualities, suggesting that meatballs retain moisture better throughout cooking. Fat, protein, and binders or emulsifiers affect drip loss. Meatballs with more fat or binding agents like starch or hydrocolloids retain moisture and have less drip loss (Berger et al., 2022; Van Buren et al., 2023). Extreme pH levels can cause protein denaturation and water ejection; therefore, a pH closer to neutral reduces drip loss. Brand A's lower drip loss reflects a more efficient formulation, making it the best option tested.

Shear Force Value (N)

Table 2 shows that meatballs from different brands had significantly different shear force values (2.83 N in Brand A and 3.36 N in Brand B, $p < 0.05$). Brand A had the lowest shear force, indicating tenderness. Meatball softness and eating quality are measured by shear force, with lower values indicating better quality and consumer acceptance. Meat type, fat content, and additives such as starch, hydrocolloids, or dietary fibers can affect shear force, resulting in tenderer texture by improving moisture retention and weakening protein networks (Ishihara et al., 2013).Lower pH causes protein denaturation, which increases shear force and makes the texture stiffer (Al-Mamun et al., 2017). These findings suggest that Brand A, with the lowest shear force, is the most tender, while the other brands showed no change.

Cooking loss

The cooking loss (%) of meatballs varied between 2.35% and 4.38%, with significant differences ($p < 0.05$) among brands. Brand A had the lowest cooking loss, indicating superior moisture and fat retention. Brand A's formulation may have better binding agents or a better fat-to-lean ratio to retain moisture and prevent cooking loss. In contrast, Brands B, C, and D lost more moisture and fat after cooking, possibly due to inadequate binding agents or fat content. Studies on meat product cooking loss and fat content and processing methods found similar results (Tănase et al., 2025).

Water Activity

Water activity (a_w) of meatballs from different brands ranged from 0.84 to 0.91, with significant differences ($p < 0.05$) determined (Table 2). Brand A had the lowest water activity, indicating stability, shelf life, and microbiological reduction. Water activity is important for food preservation because lower levels prevent microbial multiplication and deterioration (Fancello et al., 2020). Lower water activity means Brand A is the most stable, with less bacteria and mould contamination. Brands B, C, and D, with higher water activity, may degrade more easily and require more preservatives. These data indicate the relevance of water activity in meat product shelf life and microbiological safety, with Brand A being the most stable (Barcenilla et al., 2022).

Table 2: Physicochemical properties of different brands of meatballs available in the local market

Parameters	Brand A	Brand B	Brand C	Brand D	P value	Level of significance
pH	6.39^{c}±0.50	6.63^{a}±0.02	6.50^{b}±0.05	6.41^{d}±0.04	0.000	**
WHC %)	99.79^{a}±0.07	99.21^{b}±0.19	98.77^{c}±0.23	98.28^{d}±0.08	0.000	**
DL (%)	0.95^{d}±0.02	1.80^{b}±0.05	1.28^{c}±0.02	1.86^{a}±0.03	0.000	**
SFV (N)	2.83^{c}±0.05	3.36^{a}±0.05	2.93^{d}±0.05	3.13^{b}±0.05	0.000	**
CL (%)	2.35^{d}±0.01	3.92^{c}±0.06	4.25^{b}±0.02	4.38^{a}±0.10	0.000	**
WA	0.84^{d}±0.01	0.88^{c}±0.01	0.91^{a}±0.02	0.90^{b}±0.01	0.000	**

[a-d] Mean ± (SE) within a row showing different superscripts are significantly different (P<0.05)

Proximate composition

Dry matter

The dry matter content of meatballs from different brands (Table 3) ranged from 27.98% in Brand B to 34.29% in Brand A, with significant variances ($p < 0.05$). Brand A contained the highest amount of dry matter, indicating concentration. Dry matter affects sensory characteristics and stability by concentrating solids, including nutrients. Increasing dry matter content, such in Brand A, reduces water activity and microbiological development, improving product stability and shelf life (Boby et al., 2021). Brands B, C, and D, with lesser dry matter, may need preservatives or specific packaging due to microbial contamination. Higher dry matter produces a denser, firmer product. Therefore, Brand A's higher dry matter predicts better stability and flavor concentration. These findings support dry matter's effects on food stability and microbial activity (Purnomo and Rahardiyan, 2008).

Crude protein

The crude protein (CP) content of meatballs from different brands, as shown in Table 3, varied from 41.70% in Brand B to 45.03% in Brand A, with statistically significant differences ($p < 0.05$) noted. Brand A had the highest level of CP, which means it was a protein-rich product that might have more health advantages, especially for people who want to eat more protein. Protein is an important macronutrient that is necessary for muscle repair, development, and metabolic processes (Meng et al., 2022). Brand B has less protein, which means that the formula is probably focused on other ingredients, such carbs or fats. This may not be what high-protein-oriented customers want (Turhan et al., 2014) . Brands C and D had identical amounts of CP, which means that their formulations included equivalent amounts of protein (Baune et al., 2021). The higher protein level of Brand A sets it apart from the other brands, making it more appealing to people who care about their health.

Ether Extract (EE%)

Table 3 shows significant variations ($p < 0.05$) in ether extract (EE) content amongst meatball brands, ranging from 25.26% in Brand B to 29.35% in Brand A. A had the greatest EE, indicating more fat than the other brands. Ether extract indicates fat content, which affects food energy density and flavor. Energy-dense consumers may like Brand A's higher EE, which indicates a formulation with more fat to boost energy and sensory appeal (Serdaroglu et al., 2005). Brand B had the lowest EE, suggesting a low-fat formulation that may appeal to low-fat or calorie-conscious dieters. EE was identical for brands C and D, suggesting similar fat contents. These brands may standardize fat content and prioritize protein and carbohydrates. Brand A's higher ether extract shows how fat content differentiates products, with Brand B's lower fat content targeting a distinct market segment. These findings support an earlier study on dietary fat content and its effects on nutrition and taste (Baune et al., 2021; Turhan et al., 2014).

Ash

Table 3 shows that the ash content of meatballs from different brands ranged from 4.65% in Brand A to 5.58% in Brand B. Brands C and D had values of 5.37% and 5.54%, respectively, that were in the middle range. But a statistical examination showed that the ash content of the brands was not significantly different ($p > 0.05$). This indicates that the mineral makeup is quite consistent throughout the brands and is unlikely to influence nutritional assessment. These results corroborate prior research demonstrating that commercial meat products generally exhibit similar ash content owing to standardized processing methods (Serdaroglu et al., 2005). So, from a mineral content point of view, the brands didn't show any significant differences.

Table 3: Proximate composition of different brands of meatballs available in the local market

Parameters	Brand A	Brand B	Brand C	Brand D	P value	Level of significance
DM (%)	$34.29^{a}\pm0.02$	$27.98^{d}\pm0.07$	$29.46^{b}\pm0.01$	$28.34^{c}\pm0.04$	0.000	**
CP (%)	$45.03^{a}\pm0.02$	$41.70^{d}\pm0.05$	$43.47^{b}\pm0.02$	$42.15^{c}\pm0.06$	0.000	**
EE (%)	$29.35^{a}\pm0.05$	$25.26^{d}\pm0.03$	$27.34^{b}\pm0.04$	$26.52^{c}\pm0.03$	0.000	**
Ash (%)	$4.65^{d}\pm1.1$	$5.58^{a}\pm0.02$	$5.37^{c}\pm0.02$	$5.54^{b}\pm0.04$	0.254	NS

$^{a\text{-}d}$Mean ± (SE) within a row showing different superscripts are significantly different (*P*<0.05)

Color

The CIE Lab color parameters of meatballs from different brands, as shown in Table 4, indicated substantial disparities ($p < 0.05$) in lightness ($L*$), redness ($a*$), yellowness ($b*$), chroma, and hue angle. Brand A had the highest levels of redness, yellowness, chroma, and hue angle, which suggests a stronger and visually appealing color profile. This is probably because of differences in fat content and ingredient composition. Brand A had the least greenish tint, with a redness rating of -0.06, and Brand B had the most noticeable green hue, with a value of -3.39. Brand A also had the highest chroma (34.58), which means it had a brighter color, which is often what people want in food (Meng et al., 2022). However, Brand B had the lowest yellowness (13.29) and chroma (13.29), making it more neutral. Different meat composition, processing, and ingredients, such as spices or fat content, might affect color intensity and consumer appeal (Imam Hidayat et al., 2018).

Table 4: CIE Lab of different brands of meatballs available in the local market

Parameters	Brand A	Brand B	Brand C	Brand D	P value	Level of significance
CIE *L**	$71.64^{a}\pm0.03$	$71.49^{b}\pm0.02$	$71.59^{a}\pm0.02$	$71.53^{b}\pm0.02$	0.000	**
CIE *a**	$-0.06^{a}\pm0.02$	$-3.39^{d}\pm0.03$	$-0.21^{b}\pm0.01$	$-1.62^{c}\pm0.02$	0.000	**
CIE *b**	$34.41^{a}\pm0.02$	$13.29^{d}\pm0.01$	$27.44^{b}\pm0.15$	$25.23^{c}\pm0.17$	0.000	**
Chroma	$34.58^{a}\pm0.02$	$13.29^{d}\pm0.03$	$27.58^{b}\pm0.06$	$25.78^{c}\pm0.25$	0.000	**
Hue angle	$95.62^{a}\pm0.03$	$90.25^{d}\pm0.02$	$92.65^{c}\pm0.02$	$94.07^{b}\pm0.01$	0.000	**

$^{a\text{-}d}$Mean ± (SE) within a row showing different superscripts are significantly different (*P*<0.05)

Conclusion

The study evaluated meatballs from four different brands, focusing on sensory attributes, proximate composition, physico-chemical properties, and CIE (L^*, a^*, b^*) color assessment. Brand A demonstrated superior performance across all metrics. It was favored for its exceptional flavor, tenderness, and overall appeal, while also providing the highest protein content, thereby increasing its nutritional value. Brand A exhibited superior moisture retention, characterized by reduced cooking and drip loss, as well as optimal shear force and water-holding capacity. The assessment of color using the CIE (L^*, a^*, b^*) system indicated that Brand A presented the most aesthetically pleasing product, characterized by elevated brightness (L^*) and a lively yellow tone (b^*). In contrast, Brands B, C, and D demonstrated reduced tenderness, increased cooking loss, and less appealing color attributes. In conclusion, Brand A stood out as the superior meatball, presenting an optimal blend of sensory attributes, nutritional value, and physical characteristics. The results indicate that Brand A stands out as the preferred option among consumers. Subsequent investigations may delve into the combinations of ingredients and methods of processing to improve the quality of meatballs and elevate consumer satisfaction.

Competing interests

The authors have declared that no competing interests exist.

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