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Characteristics of the quality of Brahman Cross (BX) steer and heifer beef at various aging periods

[Karakteristik kualitas daging sapi Brahman Cross (BX) steer dan heifer pada berbagai periode aging]

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ABSTRACT

The consumption of premium beef in Indonesia has shown an increasing trend in line with the growth of meat-based restaurants Brahman Cross (BX) cattle are considered a potential source of premium beef due to their high growth rate, although meat tenderness remains a challenge. This study aimed to improve the tenderness of BX beef through the wet-aging method. This study utilized meat samples from BX steers and heifers aged 2–4 years, specifically the Longissimus dorsi et lumborum muscle. All samples were vacuum-packed and stored under anaerobic conditions at 0–4 °C, and subsequently analyzed at aging periods of day 1, 14, 28, and 42, with four replicates each. The data were analyzed using a split-plot design based on time with the General Linear Model program in SAS OnDemand for Academics. The results indicated a highly significant difference ($p<0.01$) in tenderness and drip loss, a significant difference ($p<0.05$) in pH, water-holding capacity, and TPC, and no significant difference ($p>0.05$) in cooking loss. The best tenderness quality was achieved on day 42, as indicated by WBSF value (4.98 ± 0.16kg/cm^{-2}), while other physical characteristics, including pH (5.36 ± 0.05), drip loss (4.81 ± 0.33%), cooking loss (41.95 ± 4.34%), and water-holding capacity (35.49 ± 0.68%), remained within normal ranges. The TPC value increased at the end of the aging period (7.22 ± 0.19 Log CFU g^{-1}). The aging process improves the physical quality of BX beef. However, it requires strict sanitation practices to ensure microbial safety.

Keywords: aging, Brahman cross, tenderness, microbiology

ABSTRAK

Konsumsi daging sapi premium di Indonesia menunjukkan tren peningkatan seiring berkembangnya restoran berbasis olahan daging. Sapi Brahman Cross (BX) merupakan alternatif sumber daging premium karena memiliki laju pertumbuhan yang tinggi, meskipun keempukan dagingnya masih menjadi tantangan. Penelitian ini bertujuan untuk meningkatkan keempukan daging sapi BX yang dilakukan dengan metode pelayuan basah. Penelitian ini menggunakan sampel daging sapi BX *steer* dan *heifer* berumur 2–4 tahun, khususnya otot *Longissimus dorsi et lumborum*. Seluruh sampel divakum dalam kondisi anaerob dan disimpan pada suhu 0–4 °C, kemudian dianalisis pada periode aging hari ke-1, 14, 28, dan 42, dengan masing-masing empat ulangan. Data dianalisis menggunakan rancangan split plot berdasarkan waktu dengan program General Linear Model pada SAS On Demand for Academics. Hasil penelitian menunjukkan bahwa terdapat perbedaan sangat nyata ($p<0.01$) pada keempukan dan drip loss, perbedaan nyata ($p<0.05$) pada pH, daya mengikat air, dan Total Plate Count (TPC), dan tidak berbeda nyata ($p>0.05$) pada susut masak. Pelayuan dengan kualitas keempukan terbaik dicapai pada hari ke-42, ditunjukkan oleh nilai WBSF (4.98 ± 0.16 kg/ cm^{-2}), dan karakteristik fisik lainnya seperti pH (5.36 ± 0.05), drip loss (4.81 ± 0.33%), susut masak (41.95 ± 4.34%), daya ikat air (35.49 ± 0.68%) masih berada dalam kisaran normal. Nilai TPC meningkat pada periode akhir (7.22 ± 0.19 Log CFU g^{-1}). Proses *aging* meningkatkan kualitas fisik daging sapi BX, namun memerlukan praktik sanitasi yang ketat untuk memastikan keamanan mikrobiologis.

Kata kunci: Brahman cross, keempukan, mikrobiologi, pelayuan

Introduction

The demand for premium beef in Indonesia has steadily increased (Utami et al., 2019), driven by modern lifestyle trends and the rapid growth of the culinary sector, particularly meat-based restaurants. Nevertheless, domestic production remains insufficient, with a deficit of 291.3 thousand tons recorded in

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2023 (Pusat Data dan Sistem Informasi Pertanian, 2023). This shortage is largely attributed to the low slaughter weight of local cattle (295.3 kg on average) and relatively low meat quality, reflected in a tenderness value of 6.98 kg/cm^2 (Fatonah et al., 2023). Moreover, inbreeding and traditional management practices further limit productivity. The primary genetic consequence of inbreeding is a decline in cattle productivity (Lakotani & Papilaya, 2024). According to the Agricultural Data and Information Center (2023), a total of 183.11 thousand tons of imported beef entered Indonesia in August 2023 alone. This highlights the limited capacity of domestic production, both in quantity and quality, to fulfill national demand. The premium beef industry in Indonesia remains heavily dependent on imports, as local production has yet to meet premium quality standards, particularly in terms of tenderness and marbling. According to Miller et al. (2001), tenderness is one of the key criteria for premium aging standards. Tenderness can be objectively evaluated using the Warner–Bratzler shear force (WBSF) test, with values <3.0 kg/cm^{-2} indicate very tender meat, 3.0–4.3 kg/cm^{-2} indicate tender meat, and 4.3–4.9 kg/cm^{-2} indicate slightly tough meat.

The Brahman Cross (BX) is a hybrid breed resulting from the cross between *Bos indicus* and *Bos taurus*. BX cattle exhibit relatively high adaptability and productivity (Maulid et al., 2021). Their optimal growth potential makes BX a promising alternative to support the supply of premium beef. BX cattle exhibit faster growth than local Indonesian cattle, with an average slaughter weight of 481.9 kg and a superior carcass yield of 54.8% (Syuaib, 2024). In addition, their higher average daily gain (ADG) provides better economic value (Amam` & Haryono, 2021). However, despite these advantages in growth efficiency, Brahman-influenced beef tends to be less tender, averaging 6.20 kg/cm^2 (Safitri et al., 2019), which underscores the need for postmortem interventions to improve meat quality. One of the post-harvest technologies known to improve beef quality is aging. Wet aging (vacuum packaging) is carried out under anaerobic conditions, which serve as a protective barrier to minimize the risk of bacterial contamination and spoilage (Yu et al., 2023). Endogenous proteolytic enzymes that break down myofibrillar structures can increasethe tenderness of beef after postmortem storage (Warner et al., 2022). The tenderization process may also be aided by other enzymes such as cathepsins, that have proteolytic activity on stromal and myofibrillar proteins(Wang et al., 2022).

In addition to tenderness and other quality attributes, such as pH value, drip loss, cooking loss, and water-holding capacity, microbiological safety is a critical consideration. Extended storage can create favorable conditions for certain spoilage and pathogenic bacteria if proper sanitation measures are not implemented (Zhang et al., 2022). Strict hygienic practices during slaughter, packaging, and storage are therefore essential to suppress microbial growth and ensure product safety. Recent studies have emphasized that sanitation protocols, equipment sterilization, and temperature control, play a decisive role in limiting the proliferation of foodborne pathogens (Yu et al., 2023). Information on tenderness development in BX beef remains limited, particularly under hygienic vacuum-aging conditions. BX cattle are generally considered to produce less tender meat, which limits their utilization in the premium beef market. Therefore, understanding the pattern of tenderness changes during aging is essential for optimizing postharvest handling strategies. Accordingly, information on the optimal aging period can serve as a basis for recommendations to the premium meat culinary industry.

Materials and methods

Materials and equipment

This experiment used *Longissimus dorsi et lumborum* muscle samples, comprising 5.600 g from steers and 5.600 g from heifers, with a total of 11.200 g. Microbiological media included Plate Count Agar (PCA) and Buffered Peptone Water (BPW). The equipment included a pH meter, bimetal thermometer, planimeter, digital scale, Warner–Bratzler shear force (WBSF) machine, and press apparatus with a 35 kg load.

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Research methodology

The experimental used a split-plot model with repeated measures over time (*split plot split in time*), followed by pairwise comparisons using least squares means to determine significant differences among treatments. Data analysis was performed using the General Linear Model (GLM) procedure in SAS On Demand for Academics (Kaps, 2004).

Research stages

a. Preparation and sample collection

Samples were obtained from several slaughterhouses in Bogor, West Java, Indonesia. *Longissimus dorsi et lumborum* muscle samples were collected from steers and heifers, with four replications per group. A total of 5.60 g from heifers and 5.60 g from steers were obtained, yielding 11.20 g.

b. Experimental procedure

Each replicate was divided into four portions of 350 g, corresponding to aging periods of 1, 14, 28, and 42 days. On day 1, the samples were chilled at 0–4 °C until the completion of rigor mortis, after which their physical and microbiological qualities were analyzed. For the subsequent aging periods (14, 28, and 42 days), the samples were vacuum-packed, stored at 0–4 °C, and subjected to the same analyses at each predetermined aging time.

Research parameters

Acidity was measured using a pH meter following AOAC (2005), calibrated with pH 4 and 7 buffers, and the electrode was rinsed with distilled water after each reading to avoid cross-contamination (Yulianti et al., 2023). Drip loss was determined by weighing samples before vacuum packaging and after storage at 0–4 °C for the designated aging period, then calculated as a percentage using the formula of Soeparno (2011) (Fikar et al., 2019).

$$\%\ \mathrm{DL} = \frac{\text{initial sample weight } - \text{ final sample weight}}{\text{initial sample weight}} \times 100\%$$

Cooking Loss refers to the reduction in meat weight after the cooking process. Cooking loss was measured using 50 g samples, which were inserted with a bimetal thermometer and boiled in water until reaching an internal temperature of 80–81 °C (Soeparno, 2011). The cooked samples were then reweighed, and the percentage of cooking loss (% CL) was calculated.

$$\%\ \mathrm{CL} = \frac{\text{initial sample weight} - \text{final sample weight}}{\text{initial sample weight}} \times 100$$

Water-holding capacity (WHC) was acquired using the Hamm method (Soeparno, 2011) by measuring the area of water released from a pressurized meat sample using a pressure gauge. Approximately 0.3 g of meat was placed between two sheets of Whatman No. 41 filter paper and pressed between two steel plates at 35 kg/cm^2 for 5 minutes. The pressed sample was then outlined, and the wet area was recorded. The amount of water released (mg H_2O) was calculated using the following equation by Hamm (1972):

$$\mathrm{mg\ H_2O} = \frac{\text{wet area }(\mathrm{cm}^2)}{0.0948} - 8.0$$

Subsequently, the proportion of free water represents the amount of loosely bound water released from the meat during pressing. The free water content was then converted to percentage values using the formula :

$$\%\ \text{free}\ \mathrm{H_2O} = \frac{\mathrm{mg\ H_2O}}{\text{sample weight}} \times 100\%$$

Warner–Bratzler shear force (WBSF) was used to assess meat tenderness following ASTM (2011) using the slice method (Aberle et al., 2001). A 250 g meat sample was heated in boiling water to an internal

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temperature of 80–81 °C, then cut parallel to the muscle fibers into cylindrical cores and sheared with a WBSF device to obtain shear force (kg/cm^2) (Yulianti et al., 2023). Total Plate Count (TPC) was determined according to SNI 2897:2008 by enumerating colonies grown on agar and expressed as colony-forming units (CFU) using standard calculations (BSN, 2008; Sukmawati & Fatimah, 2018).

Result and discussion

The quality of premium beef is determined by the interaction of various physical properties that influence quality stability during storage. Beef quality evaluation is therefore conducted through the measurement of complementary key parameters. pH, drip loss, cooking loss, water-holding capacity, tenderness, and microbiological characteristics collectively reflect the meat's ability to retain water, maintain texture and sensory attributes, and ensure food safety, which are the primary indicators of premium quality.

pH value

The results of pH value for BX beef during aging, according to gender (steer and heifer), are provided in Table 1. The pH value showed no significant differences between steers and heifers, both groups showed significant differences ($p<0.05$) across the aging periods.

Table 1. The average pH values of BX beef observed at various aging periods

Aging periods (day)	Gender		Aging periods (average ± SE)
	Steer	Heifer	
1	5.54 ± 0.08	5.54 ± 0.08	5.54 ± 0.05^{ab}
14	5.78 ± 0.08	5.53 ± 0.08	5.65 ± 0.05^{a}
28	5.47 ± 0.08	5.41 ± 0.08	5.44 ± 0.05^{bc}
42	5.42 ± 0.08	5.31 ± 0.08	5.36 ± 0.05^{c}
Gender (average ± SE)	5.55 ± 0.04	5.45 ± 0.04	
ANOVA	ns	ns	

Note: Values followed by different lowercase letters within the same column indicate significant differences ($p<0.05$). ns = not significant

The pH increased and peaked on day 14, then gradually declined by days 28 and 42, falling slightly below the isoelectric point range of muscle proteins (5.4–5.8). Ultimate meat pH does not necessarily stabilize at the isoelectric point, as it depends on post-mortem glycolysis, muscle type, and animal variability. The rise in pH on day 14 is likely due to proteolytic activity and protein degradation producing basic compounds, while the subsequent decrease suggests that pH approached and passed the isoelectric threshold. Overall, the pH values remained within the normal range for meat (5.4–5.7). Lower pH combined with high ionic strength may promote myofibrillar protein denaturation, exposing hydrophobic regions and enhancing their interaction with water.

Drip loss

Drip loss is defined as the fluid released from meat that is not reabsorbed by muscle fibers during aging. The extent of drip loss is influenced by the amount of fluid exuded from the meat and the water-holding capacity of muscle proteins (Jamhariro & Haryanto, 2024). The drip loss results for BX beef during aging, by gender (steer and heifer), are provided in Table 2. Average

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Table 2. The average drip loss (%) of BX beef observed at various aging periods

Aging periods	Gender		Aging periods (average ± SE)
	Steer	Heifer	
14	4.06 ± 0.48	2.73 ± 0.48	3.40 ± 0.33[a]
28	5.24 ± 0.48	3.53 ± 0.48	4.39 ± 0.33[ab]
42	5.06 ± 0.48	4.55 ± 0.48	4.81 ± 0.33[c]
Gender (average ± SE)	4.79 ± 0.27[a]	3.61 ± 0.27[b]	

Note: Values followed by different lowercase letters within the same column for aging period, and within the same row for gender indicate a highly significant differences ($p<0.01$).

The results of the present study demonstrated a highly significant effect ($p<0.01$) between gender and aging periods. In this study, drip loss values in BX beef ranging from 3.40–4.81%. These values fall within the normal range of fluid loss in beef, which is generally reported to be between 1-5% (Bai et al., 2023). Normal beef exhibits drip loss values ranging from 4.90 to 8.94% (Fikar et al., 2019). This finding suggests that the myofibrillar protein structure in BX beef remained relatively stable in retaining intracellular fluids, even after aging for up to 42 days. Moreover, it indicates that prolonged aging in BX beef does not lead to a significant increase in drip loss, confirming that aging up to 42 days is safe with respect to fluid loss. In line with the findings of Holman et al. (2022), aging for up to 8–14 weeks maintained physical quality without a significant increase in drip loss. Consistent fluid loss also reflects a good water-holding capacity of BX beef, which may contribute to improved meat quality characterized by enhanced freshness, firmness, and higher economic value (Khomsi, 2024).

Cooking loss

Cooking loss refers to the reduction in meat weight after cooking and serves as an important indicator of meat nutritional value, as it reflects the amount of water retained within the cells between muscle fibers (Silaban et al., 2021). The results of cooking loss for BX beef during aging, according to gender (steer and heifer), are provided in Table 3.

Table 3. The average cooking loss (%) of BX beef observed at various aging periods

Aging periods (day)	Gender		Aging periods (average ± SE)
	Steer	Heifer	
1	46.20 ± 6.14	51.56 ± 6.14	48.88 ± 4.34
14	39.69 ± 6.14	47.46 ± 6.14	43.58 ± 4.34
28	48.60 ± 6.14	44.88 ± 6.14	46.74 ± 4.34
42	41.81 ± 6.14	42.09 ± 6.14	41.95 ± 4.34
Gender(average ± SE)	44.07 ± 3.07	46.50 ± 3.07	
ANOVA	ns	ns	ns

ns = not significant

The results showed that aging duration and gender had no significant effect ($p>0.05$) on cooking loss. Cooking loss is mainly influenced by temperature and heating time, with higher temperatures and longer heating increasing moisture loss, consistent with previous studies. Although not significant, steers exhibited slightly lower cooking loss than heifers, possibly due to higher fat content in heifers, where fat melting during heating may contribute to greater fluid loss. Sex-related differences in intramuscular fat and water content may therefore influence fluid loss during cooking. Cooking loss in BX beef exhibited a fluctuating pattern, reflecting the dynamic changes in protein degradation during aging. In the early stage of aging, strong muscle fiber contraction facilitated water release during cooking, whereas enhanced proteolytic enzyme activity at day 14 loosened the myofibrillar structure, thereby improving water-holding capacity (Macharáčková et al., 2021). By day 28, protein denaturation and cellular membrane damage reduced the ability to retain water, resulting in increased cooking loss (Ježek et al., 2020).

These findings are consistent with Shanks et al. (2002), who reported that cooking loss is influenced by the extent of cellular membrane damage, the amount of water released from the meat, protein

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degradation, and the meat's water-holding capacity. Interestingly, the subsequent decline observed at day 42 may be associated with collagen degradation, which helped restore the structural balance of muscle and consequently reduced fluid loss (Liu et al., 2024). According to Azhari and Oktaviana (2019), the percentage of cooking loss in meat generally ranges from 1.5% to 54.5%, with an average between 15–40%. In the present study, the lowest average cooking loss was observed at day 42 of aging, indicating a more favorable outcome. Cooking loss is closely associated with cooking shrinkage, as both parameters reflect moisture and juice losses occurring during the cooking process. Cooking shrinkage reflects the amount of juice retained in the meat, where lower shrinkage indicates superior quality as it preserves more nutrients during cooking (Andriansah & Puspitarini, 2023).

Water holding capacity (WHC)

Water holding capacity (WHC) is a key parameter in meat quality evaluation, as it is directly associated with the proportion of free water. The results of water holding capacity for BX beef during aging, according to gender (steer and heifer), are provided in Table 4. The present analysis revealed a significant effect ($p<0.05$) of aging duration on the percentage of free water, while no significant differences were observed between gender.

Table 4. The average free water (%) of BX beef observed at various aging periods

Aging periods (day)	Gender		Aging periods (average ± SE)
	Steer	Heifer	
1	36.34 ± 0.97	38.04 ± 0.97	37.19 ± 0.68^{b}
14	35.15 ± 0.97	37.76 ± 0.97	36.45 ± 0.68^{b}
28	39.51 ± 0.97	39.46 ± 0.97	39.48 ± 0.68^{a}
42	35.60 ± 0.97	35.37 ± 0.97	35.49 ± 0.68^{b}
Gender (average ± SE)	36.65 ± 0.48	37.65 ± 0.48	
ANOVA	ns	ns	

Note: Values followed by different lowercase letters within aging period column indicate significant differences ($p< 0.05$). ns = not significant

WHC is associated with the proportion of free water, reflecting the stability of myofibrillar proteins during aging. In this study, WHC was measured using the Hamm (1972) press method, where applied pressure quantifies released water and indicates the meat's moisture-retention capacity. A higher free water proportion denotes lower WHC, whereas a lower proportion indicates better water retention. The free water percentage of BX beef fluctuated from day 1 to day 42, with a significant increase on day 28, likely due to myofibrillar protein degradation that enlarged capillary spaces for water retention. The decline on day 42 corresponded to pH approaching the isoelectric point, reducing protein charges and WHC. Such fluctuations during extended aging are commonly linked to interactions between protein degradation and lipid/protein oxidation and are consistent with previous findings on Bali beef.

Warner–Bratzler shear force (WBSF)

Meat tenderness, determined using WBSF, is highly dependent on the muscle's ability to retain water. The lower the water-holding capacity, the less tender the meat texture becomes (Sari et al., 2017). In this study, meat tenderness was closely associated with water retention, whereby samples exhibiting higher water WHC and lower free water percentages (Table 4) showed lower shear force values, indicating greater tenderness. The results of WBSF for BX beef during aging, according to gender (steer and heifer), are provided in Table 5.

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Table 5. The average WBSF of BX beef observed at various aging periods (kg/cm^{-2})

Aging periods (day)	Gender		Aging periods (average ± SE)
	Steer	Heifer	
1	7.90 ± 0.23^{a}	7.82 ± 0.23^{a}	7.86 ± 0.16
14	6.77 ± 0.23^{b}	7.52 ± 0.23^{a}	7.15 ± 0.16
28	5.70 ± 0.23^{c}	7.50 ± 0.23^{a}	6.60 ± 0.16
42	5.00 ± 0.23^{d}	4.97 ± 0.23^{d}	4.98 ± 0.16
Gender (average ± SE)	6.34 ± 0,11	6.95 ± 0.11	

Note: Values followed by different lowercase letters indicate a highly significant correlation and difference ($p<0.01$).

The tenderness values of BX beef indicated a correlation between steers and heifers. Tenderness decreased significantly ($p<0.01$) with extended aging periods. The results of this study indicate that aging for up to 42 days resulted in a WBSF value of 4.98 kg/cm^{-2}. This value is very close to the transition threshold from the tough to moderately tough category (4.3–4.9 kg/cm^{-2}), a range in which consumer acceptance remains relatively high, at approximately 59–86% (Miller et al., 2001). This decline reflects the natural tenderization process driven by proteolytic enzymes, such as calpains and cathepsins, which degrade myofibrillar proteins and consequently loosen the muscle structure (Xiong et al., 2020). Beef is naturally tenderized by a number of biochemical processes as it ages (Foraker et al., 2020). The structural and regulatory proteins that make up myofibrillar structures are broken down by proteolytic enzymes. Important beef flavor precursors (free amino acids, sugars, and peptides) are rendered available by postmortem age and proteolysis. (Vierck et al., 2020). This finding suggests that 42 days of aging provides practically optimal tenderness, although it does not yet satisfy the official tenderization claim. Referring to the ASTM benchmark, it can be inferred that aging plays a crucial role in tenderization; however, the optimal condition may require a longer aging period (>42 days).

The genetic effect of Bos indicus in BX cattle makes it more difficult to achieve the ideal level of tenderness. BX cattle are traditionally classified as working-type animals, and their meat is characterized by relatively higher toughness and rigidity, which hinders postmortem protein degradation (Vesga et al., 2024). This *Bos indicus* influence can slow the aging process and reduce tenderization efficiency, although extended aging still leads to a significant improvement in tenderness. *Bos indicus* cattle exhibit higher calpastatin activity than *Bos taurus* cattle (Hughes et al., 2014). Elevated calpastatin activity in *Bos indicus* inhibits protein proteolysis during postmortem aging, thereby adversely affecting meat tenderness (Gama et al., 2013; Wright et al., 2018). Animal age is also a crucial factor affecting meat tenderness. Meat from younger animals is generally more delicate than that from older animals. This difference is largely associated with the accumulation of connective tissue, particularly collagen, which increases with age. Collagen in younger animals is more soluble during cooking, thereby producing softer meat. In contrast, in older animals, collagen develops more complex cross-linking, making connective tissue stronger and more resistant to degradation, which ultimately results in tougher meat texture (Suantika et al., 2017). In line with the role of aging duration in tenderization, differences between sex classes were also evident, with steers exhibiting a faster decline in WBSF compared to heifers. Biological factors such as collagen content and muscle fiber distribution influence the rate of tenderization (Zhao et al., 2022). Thus, the combined effects of aging and physiological differences between animals determine the final tenderness quality of BX beef.

Total plate count

Total plate count (TPC) is closely related to changes in the physical quality attributes of beef during the aging process, as microbial activity may influence muscle structure and water retention, including pH value, tenderness, water-holding capacity, free water percentage, and cooking loss. The results of TPC for BX beef during aging, according to gender (steer and heifer), are provided in Table 6.

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Table 6. The average total TPC (Log CFU g^{-1}) of BX beef observed at various aging periods

Aging periods (day)	Gender		Aging periods (average ± SE)
	Steer	Heifer	
1	6.04 ± 0.27	6.11 ± 0.27	6.07 ± 0.19[a]
14	6.70 ± 0.27	6.09 ± 0.27	6.39 ± 0.19[a]
28	7.48 ± 0.27	6.68 ± 0.27	7.08 ± 0.19[b]
42	7.20 ± 0.27	7.24 ± 0.27	7.22 ± 0.19[b]
Gender (average ± SE)	6.85 ± 0.13	6.53 ± 0.13	
ANOVA	ns	ns	

Note: Values followed by different lowercase letters within the same column indicate significant differences ($p<0.05$). ns = not significant

The findings exposed that the TPC of BX beef increased significantly ($p<0.05$) with the extension of the aging period. This increase is closely associated with postmortem biochemical changes, especially the way natural enzymes break down connective tissue and myofibrillar proteins, which release peptides and free amino acids that serve as substrates for microbial growth (Zhao et al., 2022). Moreover, postmortem proteolysis alters the structural integrity of muscle fibers, rendering them looser and thereby facilitating microbial penetration and colonization.

According to the Indonesian National Standar, the maximum permissible microbial contamination in fresh meat is 6 log CFU g^{-1} (BSN, 2008). The present study revealed that the TPC on the first day of aging had already exceeded this threshold, indicating the potential for contamination at the early post-slaughter stage. The elevated microbial load may originate from primary contamination derived from the animal itself, as well as secondary contamination occurring during carcass processing at slaughterhouses. Contributing primary factors include the hygienic condition of the skin, hair, and respiratory tract of the animal (Pal et al., 2022). Secondary contamination occurs as a result of cross-contamination during slaughtering, hide removal, evisceration, cutting, chilling, as well as from processing equipment (Pazra & Wahyuningsih, 2024). In addition, contamination originating from workers and water plays a significant role in increasing microbial colony counts on carcasses (Aramadani et al., 2019). Sanitation measures are a critical component in reducing the risk of contamination.

The implementation of Good Slaughtering Practices (GSP) and Sanitation Standard Operating Procedures (SSOP) in slaughterhouses, including equipment sanitation, personnel hygiene, the use of clean water, and strict control of slaughtering and chilling room temperatures has been shown to effectively reduce microbial hazards (Fitri et al., 2021). Furthermore, modern storage techniques such as vacuum packaging and modified atmosphere packaging (MAP) under low temperatures have been reported to suppress microbial growth while preserving the organoleptic quality of meat (Saputra & Widodo, 2023). Therefore, a combination of rigorous sanitation control within slaughterhouses and the application of appropriate post-production technologies represents a crucial strategy to achieve a balance between sensory quality and food safety in BX beef.

Conclusion

This study confirms that aging significantly influences the physical and microbiological quality of BX beef. The optimal aging period occurred at day 42, resulting in a significant reduction in WBSF to 4.98 kg/cm^{-2}, while other physical parameters including pH (5.36), drip loss (4.81%), cooking loss (41.95%), and water-holding capacity (35.49%), remained within normal ranges; however, the tenderness achieved did not yet meet the tender meat classification. TPC values exceeding acceptable microbial limits indicate potential contamination (7.22 Log CFU g^{-1}), emphasizing the need for strengthened sanitation control. Overall, extended aging improves tenderness and provides a useful reference for the premium meat industry, but must be accompanied by strict hygienic handling and optimized storage conditions to ensure microbial safety and product quality.

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