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Assessing the impact of Bos taurus x Bos indicus crossbreeding and postmortem technologies on the eating quality of loins from pasture-finished young bulls

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Abstract: The aim of this study was to evaluate the effects of Brahman crossbreeding and postmortem technologies (electrical stimulation and vacuum aging) on the eating quality of loins from pasture-finished bulls. Fifty yearling bulls representing five Brahman-influenced types (n = 10 each): Brahman (BRAH), F1-Angus (F1ANG), F1-Chianina (F1CHI), F1-Romosinuano (F1ROM), and F1-Simmental (F1SIM) were supplemented on pasture until reaching a desirable conformation at a suitable live weight of ca. 480 kg. All carcasses were classified as “Bullocks” according to U.S. standards. Carcass’s right sides were subjected to high-voltage electrical stimulation (ES), while the left sides were not stimulated (NOES). Longissimus lumborum (LL) steaks from ES and NOES carcasses were allotted either to the vacuum aging control treatment for 2 d (NOAGING) or 10 d (AGING). The LL steaks were evaluated for Warner-Bratzler shear force (FCWB) and sensory traits rated by trained panelists. No differences in WBSF, juiciness, or flavor ratings were detected among breed types ($P > 0.05$). Sensory ratings for tenderness-related traits varied with breed type ($P < 0.05$). Steaks from F1ANG received higher ratings for muscle fiber tenderness, overall tenderness, and amount of connective tissue than those from F1ROM and F1SIM ($P < 0.05$), which received the lowest ratings. Bullock loins were more responsive to ES+AGING in WBSF reduction and desirable tenderness ratings than other postmortem treatments ($P < 0.05$) by reaching a greater proportion (72 %) of “tender” (WBSF < 40.1 N) steaks than AGING (48 %), ES (36 %), and NOES-NOAGING (24 %) samples ($P < 0.01$). Tenderness of bullock loin steaks was marginally improved by crossbreeding. Therefore, the application of ES+AGING is necessary to ensure a higher proportion of tenderloin steaks.

Key words: vacuum aging, Brahman, beef, electrical stimulation, shear force, eating quality, beef tenderness.

Evaluación del impacto de cruzamientos Bos taurus x Bos indicus y tecnologías postmortem sobre la calidad gustativa de lomos de toros jóvenes terminados a pasto

Resumen. El objetivo de este estudio fue evaluar los efectos de cruzamientos interraciales y tecnologías postmortem sobre la calidad gustativa de lomos de toros terminados a pasto. Cincuenta toros añosos representando cinco tipos raciales (n = 10 cada uno): Brahman puro (BRAH), F1-Angus (F1ANG), F1-Chianina (F1CHI), F1-Romosinuano (F1ROM) y F1-Simmental (F1SIM) se suplementaron a pastoreo hasta alcanzar una conformación satisfactoria a un peso vivo de ca. 480 kg. Todas las canales se clasificaron como “Bullocks” (Toretes) por la norma estadounidense. Los lados derechos de cada canal se sometieron a estimulación eléctrica de alto voltaje (ES) mientras que los lados izquierdos no fueron estimulados (NOES). Bistés de longissimus lumborum ES y NOES se asignaron a tratamientos de maduración al vacío por 2 d (NOMADURADOS) ó 10 d (MADURADOS). Los bistés se evaluaron para fuerza de corte Warner-Bratzler (FCWB) y rasgos sensoriales calificados por panelistas capacitados. No se detectaron diferencias en valores FCWB, o calificaciones para jugosidad o intensidad de sabor entre tipos raciales ($P > 0.05$). Los rasgos relacionados con terneza variaron con el tipo racial ($P < 0.05$). Los bistecs de F1ANG recibieron calificaciones más altas para terneza de fibra muscular, terneza general y cantidad de tejido conectivo que de los F1ROM y F1SIM ($P < 0.05$), de calificaciones más bajas. Los bistés ES+MADURADOS tuvieron menor FCWB y mayores calificaciones para rasgos asociados con la terneza que los ES ó los MADURADOS ($P < 0.05$), alcanzando una mayor proporción (72 %) de "bistés tiernos" (FCWB < 40.1 N) que la de MADURADOS (48 %), ES (36 %) y

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NOMADURADOS (24 %) (P < 0.01). La mejora en terneza de lomos de toretes Brahman mediante cruzamiento con razas taurinas es marginal. Por tanto, se recomienda aplicar el tratamiento combinado de ES y maduración al vacío para asegurar una proporción mayor de bistés tiernos.

Palabras clave: bovino, Brahman, estimulación eléctrica, maduración al vacío, calidad sensorial, terneza de la carne.

Avaliação do impacto dos cruzamentos Bos taurus x Bos indicus e tecnologias post mortem na qualidade gustativa de lombos de novilhos terminados a pasto

Resumo. O objetivo desse estudo foi avaliar os efeitos de cruzamentos interraciais e tecnologias *postmortem* na qualidade do sabor de lombos de touros terminados a pasto. Cinquenta touros envelhecidos, representando cinco tipos de raça (n = 10 cada): Brahman puro (BRAH), F1-Angus (F1ANG), F1-Chianina (F1CHI), F1-Romosinuano (F1ROM) e F1-Simmental (F1SIM) foram suplementadoscom pasto até atingir uma conformação satisfatória com um peso vivo de ca. 480kg. Todas as carcaças foram classificadas como “Boi” (Toretes) pela norma americana. Os lados direitos de cada canal foram submetidos à estimulação elétrica de alta voltagem (ES), enquanto os lados esquerdos não foram estimulados (NÃO-ES). Bifes de *longissimus lumborum* ES e NÃO-ES foram submetidos a tratamentos de maturação a vácuo por 2 d (NÃO-MATURADOS) ou 10 d (MATURADOS). Os bifes foram avaliados quanto à resistência ao cisalhamento Warner-Bratzler (FCWB) e características sensoriais avaliadas por provadores treinados. Não foram detectadas diferenças nos valores de FCWB, ou classificações de suculência ou intensidade de sabor entre os tipos de raça (P > 0.05). As características relacionadas à ternura variaram com a raça (P < 0.05). Os bifes F1ANG receberam pontuações mais altas para maciez da fibra muscular, maciez geral e quantidade de tecido conjuntivo que os do F1ROM e F1SIM (P < 0.05), que receberam as pontuações mais baixas. Os bifes ES + MATURADOS apresentaram menor FCWB e maiores classificações para características associadas à maciez do que os bifes ES ou MATURADOS (P < 0.05), atingindo uma proporção maior (72 %) de "bifes macios" (FCWB < 40.1 N) do que os bifes MATURADOS (48 %), ES (36 %) e NÃO- ES- NÃO-MATURADO (24 %) (P < 0.01). A melhora na maciez dos lombos de touros Brahman pelo cruzamento com raças taurinas foi marginal; portanto, recomenda-se o tratamento combinado de ES e envelhecimento a vácuo para garantir uma maior proporção de bifes macios.

Palavras-chave: bovinos, Brahman, estimulação elétrica, maturação a vácuo, qualidade sensorial, maciez da carne.

Introduction

Beef cattle in Venezuela are mostly fed on pasture, have a strong *Bos indicus* (Zebu) influence and most males are left uncastrated (bulls/bullocks) for beef production (Rodas-González *et al.*, 2009; Huerta-Leidenz *et al.*, 2020). These production practices have detrimental effects on meat palatability, particularly tenderness (Pereira *et al.*, 2015). *Bos taurus* x *Bos indicus* crossbreeding is alleged to benefit the quality of beef carcass and meats, but most studies supporting this claim have been carried out with feedlot-finished steers in North America (Riley *et al.*, 2012). In South America, there is inconsistent evidence of crossbreeding benefits on the meat quality of Brahman-influenced bulls under grass-feeding conditions (Jerez-Timaure *et al.*, 2009; Gama *et al.*, 2013). Several antemortem factors encompass critical quality points that may escape from the control of the beef processing industry, and thus, the application of postmortem technologies such as carcass electrostimulation (ES) and vacuum aging of meat, could be an alternative to improve its tenderness and other sensory traits. According to the Venezuelan Association of Meatpacking Plants (ASOFRIGO), most beef carcasses are sold within 3-5 d *postmortem* (Rivas, F., personal communication), without further extended aging or the application of any other *postmortem* technology (Rodas-González *et al.*, 2009). The use of ES and vacuum aging in meat from Zebu-influenced, grass-finished bullocks/bulls has not been extensively evaluated in Tropical America (Huerta-Leidenz *et al.*, 1997; Rodas-González *et al.*, 2007).

Improvement of tenderness by meat aging involves several proteolytic systems responsible for the degradation of muscle proteins (Sami *et al.*, 2015). Generally, the tenderness of beef improves significantly over the aging period in a muscle-specific manner (Nair *et al.*, 2019). In two previous studies (Riera *et al.*, 2004; Riera *et al.*, 2021), bulls of five Brahman-influenced types were finished on cultivated pastures and compared in growth and carcass traits. In the present study, the same groups of bull carcasses were used to (a) compare the eating quality of loins among the five Brahman-influenced types, and (b) examine the degree of improvement in eating quality with the individual or combined application of ES and vacuum aging.

Materials and Methods

Animal management

Details on animal breeding, selection, and management during the experiment were described by Riera-Sigala et al. (2004). Briefly, 50 bull calves were randomly selected from a larger group of 91 (Brahman and its F1 crosses) obtained by artificial insemination to represent five breed types (n = 10 per breed type): Purebred Brahman (BRAH), Angus x BRAH (F1ANG), Chianina x BRAH (F1CHI), Romosinuano x BRAH (F1ROM), Simmental x BRAH (F1SIM). For the finishing phase, all the 50 yearling bulls (ca. 23 mo. of age) entered the selected grazing area as a single group to be fattened on cultivated pasture predominantly planted with tanner grass (Brachiaria radicans). Paddocks were managed on a rotational schedule of 28 days with seven-day occupation and 21-day rest intervals resulting in a stocking rate of 2.4 animals per ha. During the dry season, the bulls were supplemented on pasture. Detailed information about the ingredient composition and bromatological analysis of the forage and supplement was reported by Riera-Sigala et al. (2004).

The supplementation strategy consisted of feeding a supplement (4 kg/d/animal) offered in mobile feeders. Animals were sent to harvest when reaching a desirable conformation at a suitable final weight of ca. 480 kg. The first lot of finished young bulls (n = 20) was sent for harvest after completing 99 days of pasture feeding (DOPF), the second (n = 20) at 121 DOPF, and the last one (n = 10) at 149 DOPF. Age at harvest (mean ± standard deviation) for the lots of finished bulls on harvest d 1, harvest d 2, and harvest d 3 were 25 ± 0.44, 27.25 ± 0.55, and 27.70 ± 0.67 mo. respectively.

Livestock handling and weight measurements as well as slaughter and dressing procedures were performed in compliance with the criteria for animal care and welfare described in the Bioethics and Biosafety guide of the Fondo Nacional de Ciencia, Innovación y Tecnología of Venezuela (FONACIT, 2002) (Project Protocol CONDES-LUZ # CC-0390-04). The postmortem inspection followed the Venezuelan industry standards (COVENIN, 1983).

Postmortem treatments and carcass evaluation

Approximately 20 min postmortem, after carcass evisceration, the carcass' right side was subjected to high-voltage electric stimulation (ES). The ES was carried out with a Lectro-tender TM apparatus (Le-Fiell Company Inc. Reno, NV, USA), applying 12 electrical pulses in 41.4 s (1.8-s of duration, with 1.8-s of intervals between pulses) of 550 Volts and 60 Hertz of alternating current of 1 to 2 amps. The left carcass side was not electrically stimulated (NOES). All carcass sides were weighed and loaded into a cooler on rails spaced at about 30 cm for heat-dissipation with intermittent spray chilling for approximately 6 h with an air temperature of 0-2 ºC (average 1 ºC), relative humidity of 95 %, and an average air velocity over the carcass at about 3 - 4 m/s. Thereafter, the carcass sides were transferred to storage chillers at an average air temperature of 4 ºC, relative humidity of 80 - 85 %, and an average air velocity of 1 m/s until carcass evaluation and fabrication at ca. 48 h postmortem. The carcass pH range and average carcass temperature just before fabrication were 5.6 - 5.8 and ca. 7 °C, respectively.

The carcass data collection was described in detail by Riera-Sigala et al. (2004, 2021). In brief, two experienced judges assigned scores for carcass conformation, fat cover amount (finish), and adipose maturity according to Decreto 1896 (1997). Ribeye area, backfat thickness, marbling level, skeletal and lean maturities were evaluated following the guidelines of the USDA (2017). Chilled carcasses were then reduced to subprimal/retail cuts according to the standard fabrication procedures (Montero et al., 2014). A 20 cm length portion was removed from the rib-loin interface (12-13th rib) towards the caudal portion of the longissimus lumborum muscle (LL), from which eight 2.5 cm thick steaks were obtained. Each steak was allocated to each of the two (2-d or 10-d) aging treatments and vacuum packaged. Anatomical position bias was avoided by alternating analysis designations and by rotating ES or aging treatments. The ES and NOES steaks assigned to the 2-d aging control group (NOAGING) were immediately frozen (-30 °C) and stored for further analysis. The remaining steaks were assigned to the 10-d aging treatment (AGING) and stored in a cooler where the temperature was maintained thermostatically between 2 °C to 4 °C. At the end of the 10-d aging period, the aged steaks were frozen (-30 °C) and stored for later analysis.

Culinary, shear force tests, and sensory evaluation

Sample preparation, cooking procedure, sensory evaluation, and Warner- Bratzler shear force (WBSF) protocols were followed according to the American Meat Science Association (AMSA) guidelines (AMSA, 2016). A Sunbeam-Oster® open electric grill (Sunbeam-Oster Co. Inc., Fort Lauderdale, FL, USA) was used for steak cooking. Once the steaks reached the internal temperature of 70 ºC, they were removed from the grill and cooled down at room temperature. Six to ten core samples (1.27 cm in diameter) were removed parallel to the muscle fiber orientation. The shear force measurements were performed using a Warner-Bratzler shear machine (G-R Elec. Mfg. Co, Manhattan, KS).

For sensory evaluation, 8 to 15 cubed samples (≈1.27 cm^3 in size) were obtained from each steak. Cubed samples from each experimental unit were placed on pre-coded discardable, cardboard plates and kept warm in a preheated oven (at 50 ºC) for 7 min before serving them to the panelists. The trained sensory panel was composed of eight trained panelists. The panelists' selection process and training had been accomplished according to Huerta-Leidenz et al. (1996). Two samples were taken from each steak and served warm to each panelist. All samples were evaluated during 10 d by the trained panelists, who were served alternating samples from different breed types and postmortem treatments. Panelists scored the samples, using an 8-point structured rating scale for juiciness, muscle fiber tenderness, overall tenderness, amount of connective tissue, and flavor intensity following AMSA guidelines (AMSA, 2016).

Statistical analyses

Data collected were analyzed using SAS, Version 9.4 (SAS, 2012). Simple descriptive statistics (mean, standard deviation, maximum and minimum values, and coefficient of variation) for final live weight, age at harvest, and carcass traits were calculated (PROC MEANS) to characterize the experimental group. The statistical model used for analyzing the sensory and WBSF data was a completely randomized design with a split-plot arrangement using PROC MIXED. Breed type was in the whole-plot portion and postmortem treatment was assigned in the subplot. Breed type, postmortem treatment, and their interactions were considered fixed effects. The individual carcass and the harvest date within postmortem treatment were used as random effects in the model. The least-square means were separated (F test, $P < 0.05$) using the least significant differences generated through the PDIFF option.

Chi-square (χ^2) analysis (Fisher's exact test) was used to test differences in frequencies of harvested bulls among breed types within the three harvest days. Also, the Fisher's exact test was used for testing differences for breed type x postmortem treatment to describe the proportion of tender steaks according to the threshold values for tenderness classes (Tender: WBSF < 37.98 N and Tough: WBSF > 37.98 N) developed by Rodas-González et al. (2009).

Results

Frequency distribution of the number of bulls harvested per breed type and harvest day

The distribution of harvest-ready bulls by breed type and successive harvest days is presented in Table 1. No significant differences in frequency distributions within the harvest days were detected ($P = 0.06$) among breed types.

Characterization of the bull samples

Descriptive statistics for traits of the bull sample are presented in Table 2. The chronological age for all the 50 harvest bulls was less than 30 months. The highest variation (CV = 47 %) in carcass traits was observed for backfat thickness (within a narrow range of values: 0-3 mm). As expected, the discrete variables related to carcass fatness such as external fat cover (i.e., finish score; "very abundant to devoid"; CV = 27 %) and marbling scores ("small" to "traces"; CV = 8.91 %) did not vary as much.

Table 1. Distribution of harvest-ready bulls by breed type and harvest day[1,2]

Harvest day[4]	Breed type[3]					
	BRAH	F1ANG	F1CHI	F1ROM	F1SIM	Total
1	0	5	6	3	6	20
2	6	3	3	6	2	20
3	4	2	1	1	2	10
Total	10	10	10	10	10	50

[1]Sourced and adapted from Riera Sigala et al. (2004).

[2]Chi-square analysis indicated the frequency distribution per harvest day was not different among breed types ($P = 0.06$).

[3]Purebred Brahman (BRAH), F1-Angus (F1ANG), F1-Chianina (F1CHI), F1-Romosinuano (F1ROM) and F1-Simmental F1SIM).

[4]Harvest day corresponds to the processing day of lots of finished bulls after completing the grazing period (number of days on pasture) required to reach a desirable conformation at a suitable final weight of ca. 480 kg (Harvest d 1 = after 99 d on pasture; Harvest d 2 = after 121 d on pasture; Harvest d 3= after 149 d on pasture).

Table 2. Descriptive statistics for the group of Brahman-influenced young bulls

Trait	Mean	Minimum value	Maximum value	Standard deviation	Coefficient of variation
Age at harvest, mo.	27.14	26	28	0.64	2.35
Live weight, kg	479.04	464.00	520.00	11.08	2.31
Carcass weight, kg	267.68	248.00	293.00	29.91	11.17
Finish score [a]	2.76	1.00	5.00	0.74	26.95
Ribeye area, cm^2	72.39	56.77	89.03	7.43	10.26
Backfat thickness, mm	1.44	0.0	3.00	0.67	46.86
Conformation score [b]	1.78	1.00	3.00	0.50	28.46
Marbling [c]	4.88	3.00	5.00	0.43	8.91
Adipose maturity [d]	2.80	2.00	3.00	0.40	14.43
Skeletal maturity [e]	162.60	130.00	190.00	13.21	8.12
Lean maturity [e]	154.00	120.00	180.00	16.03	10.41

[a] 1=Extremely abundant, 2=Abundant, 3=Medium, 4=Slight, 5=Scarce (Decreto No.1896, 1997); [b] 1=Very convex, 2=Convex, 3=Rectilinear, 4 =Concave, 5=Very concave Decreto No.1896, 1997); [c] 1=Abundant, 2=Moderate, 3=Small, 4=Slight, 5=Traces, 6=Practically devoid (USDA, 2017); [d] 1=Ivory white, 2=Creamy white, 3=Light yellow, 4=Intense yellow, 5=Orange (Decreto No.1896, 1997); [e] 100–199 maturity range score represents the youngest group: 100=A00 and 199 =A99; 200–299 represent carcasses with intermediate, more advanced maturity: 200=B00 and 299=B99 (USDA, 2017). Total number of observations = 50.

Variation of sensory traits of loins

Variation in WBSF and sensory traits of bullock loins according to breed type, postmortem treatment, and first-order interaction is shown in Table 3.

No significant breed type x postmortem treatment interaction was observed for the sensory variables under study (P > 0.05). Breed type and postmortem treatment affected the variation of ratings for tenderness and amount of connective tissue (P < 0.01). Ratings for juiciness and flavor intensity did not vary with breed type or postmortem treatment (P > 0.05). Steaks from F1ANG received higher ratings for muscle fiber tenderness, overall tenderness, and amount of connective tissue than those from F1ROM and F1SIM (P < 0.05), which received the lowest ratings. F1ANG steaks were described as “slightly tender”, “slightly tough”, and “moderate amount of connective tissue”, respectively. In contrast, F1SIM steaks were described as “slightly tough”, “moderately tough”, and “slightly abundant”, respectively. Steaks from BRAH and F1CHI, types received intermediate rating values and did not differ from those of F1ANG (P > 0.05) (Table 3).

Table 3. Effects of breed type and postmortem treatment on Warner Bratzler shear force (WBSF) and sensory traits1 of cooked loin steaks from young bulls.

Variable	Breed Type (BT)[2]					Postmortem treatment (PT)[3]				SEM	P-value		
	BRAH	F1ANG	F1CHI	F1ROM	F1SIM	ES+AGING	AGING	ES	Control		BT	PT	BTxPT
Juiciness	5.18	5.04	5.25	5.07	5.13	5.11	5.10	5.20	5.12	0.11	0.61	0.51	0.08
MFT	4.89^{abc}	5.13^{a}	5.03^{ab}	4.48^{bc}	4.31^{c}	5.15^{a}	4.94^{b}	4.61^{c}	4.36^{d}	0.18	0.02	< 0.01	0.61
OVT	4.55^{abc}	4.78^{a}	4.67^{ab}	4.05^{bc}	3.91^{c}	4.87^{a}	4.62^{b}	4.19^{c}	3.90^{d}	0.20	0.04	< 0.01	0.57
AMCT	4.18^{ab}	4.42^{a}	4.29^{ab}	3.75^{bc}	3.54^{c}	4.42^{a}	4.25^{a}	3.86^{b}	3.63^{c}	0.19	0.02	< 0.01	0.59
FLVORI	5.90	5.89	5.87	5.91	5.94	5.90	5.90	5.90	5.90	0.03	0.99	0.60	0.37
WBSF, N	43.93	37.95	41.58	45.11	50.11	37.85^{a}	41.78^{b}	45.80^{b}	49.33^{c}	2.84	0.21	< 0.01	0.62

[1]Based on a descriptive scale for juiciness, muscle fiber tenderness (MFT), overall tenderness (OVT), amount of connective tissue (AMCT), and flavor intensity (FLVORI); where, 1=extremely dry, extremely tough, extremely tough, extremely tough, abundant amount of connective tissue, and extremely bland, respectively; and 8=extremely juicy, extremely tender, extremely tender, extremely tender, negligible amount of connective tissue, and extremely intense, respectively. [2]Purebred Brahman (BRAH), F1-Angus (F1ANG), F1-Chianina (F1CHI), F1-Romosinuano (F1ROM) and F1-Simmental F1SIM). [3]Vacuum aging for 10 d (AGING), Electrical stimulation (ES); Electrical stimulation plus 10-d vacuum aging (ES+AGING), Control (no ES, no AGING). [a,b,c,d] Least squares means within a row lacking a common superscript letter differ (P < 0.05).

Regarding the effects of postmortem technologies, beef samples from the dual-treatment (ES+AGING) received higher ratings for tenderness-related traits compared to ES, AGING, and control (NOES-NOAGING) samples (Table 3; P < 0.05). ES+AGING samples were described as “slightly tender” for muscle fiber tenderness, “slightly tough” for overall tenderness, with a “moderate” amount of connective tissue (P > 0.05). AGING samples ranked second in response to the tenderizing effects, followed by ES and NOES-NOAGING control counterparts.

Variation of shear force values and tenderness classes

No breed type x postmortem treatment interaction on WBSF was detected (P > 0.05) (Table 3); and no differences in WBSF were detected among breed types (P > 0.05). The WBSF was affected by the postmortem treatment (P < 0.01). WBSF mean values were the lowest for ES+AGING (Table 3; P < 0.05), while ES- or AGING-treated samples exhibited intermediate WBSF values. In relation to the NOES-NOAGING (control) group, the WBSF mean values decreased to 11.48 N when samples were subjected to the ES+AGING treatment, 7.55 N when samples were only aged, and 3.53 N when carcasses were only treated with ES (Table 3).

Although WBSF was not significantly affected by breed type (Table 3), the distribution of steaks by tenderness class (Table 4) showed that F1ANG yielded the highest proportion of tender steaks, whereas F1SIM yielded the lowest (P < 0.01). Regarding postmortem treatments, ES+AGING resulted in the highest percentage of tender steaks followed by AGING and then ES (P < 0.01).

Table 4. Distribution of tender steaks according to breed type and postmortem treatment

Source	Tender steaks, n (%)
Breed type [1]	
Brahman	17 (42.5)
F1-Angus	26 (65.0)
F1-Chianina	20 (50.0)
F1-Romosinuano	17 (42.5)
F1-Simmental	10 (25.0)
Postmortem treatment [2]	
Electrical stimulation plus	
10-d vacuum aging	36 (72.0)
10-d vacuum aging	24 (48.0)
Electrical stimulation	18 (36.0)
Control	12 (24.0)

The proportion of tender steaks was calculated using a threshold value for tenderness classes (Tender: WBSF < 37.98 N and Tough: WBSF > 37.98 N) as described by Rodas et al. (2009). [1]Chi-square analysis indicated the distribution of tender steaks was different among breed types (P < 0.01). [2]Chi-square analysis indicated the distribution of tender steaks was different among postmortem treatments (P < 0.01).

The distribution of tender steaks according to breed type x postmortem treatment is presented in Table 5. It is noteworthy that within the NOES-NOAGING groups, half of the F1ANG steaks tended to be classified as tender (P = 0.07), whereas lower proportions of tender steaks (0 to 30 %) were found in NOES-NOAGING samples derived from the other breed types. The proportion of tender steaks from F1ANG progressively improved in 10 % increments in the following treatment order: ES, AGING, and ES+AGING. However, relative incremental proportions of tender steaks with the individual (ES or AGING) and ES+AGING technologies tended to be greater in other breed types. In fact, when compared to the NOES-NOAGING control, the proportion of tender steaks from BRAH increased by 30 percentage units with ES or AGING, and 70 percentage units when subjected to the ES+AGING treatment. In the end, all-breed types reached a similar proportion of tender steaks (P = 0.95) with the ES+AGING treatment.

Table 5. Distribution of tender steaks according to breed type x postmortem treatment1

Postmortem treatment[3]	Breed type[2]					
	BRAH n (%)	F1ANG n (%)	F1CHI n (%)	F1ROM n (%)	F1SIM n (%)	P-value 4
ES+AGING	8 (80.0)	8 (80.0)	7 (70.0)	7 (70.0)	6 (60.0)	0.95
AGING	4 (40.0)	7 (70.0)	5 (50.0)	5 (50.0)	3 (30.0)	0.53
ES	4 (40.0)	6 (60.0)	5 (50.0)	3 (30.0)	1 (10.0)	0.12
Control	1 (10.0)	5 (50.0)	3 (30.0)	2 (20.0)	0 (0.00)	0.07
P-value5	0.01	0.68	0.41	0.14	0.01	

[1]The proportion of tender steaks was calculated using a threshold value for tenderness classes (Tender: WBSF < 37.98 N; Tough: WBSF > 37.98 N) as described by Rodas et al. (2009). [2]Purebred Brahman (BRAH), F1-Angus (F1ANG), F1-Chianina (F1CHI), F1-Romosinuano (F1ROM) and F1-Simmental F1SIM). [3]Electrical stimulation plus 10-d vacuum aging (ES+AGING), 10-d vacuum aging (AGING), Electrical stimulation (ES); Control (no ES, no AGING) [4]Comparison of frequency distribution among breed types within each postmortem treatment by Chi-square analysis. [5]Comparison among postmortem treatments within breed type by Chi-square analysis.

Discussion

Overall, the group of Brahman-influenced bulls supplemented on tropical pasture were harvested at a young chronological age (< 30 mo.). All carcasses fell into the youngest maturity category (“A”) according to the skeletal, lean, and adipose maturity (described as “creamy” fat color) indicators and thus would be eligible to be classified as “Bullocks” by the USDA standards (USDA, 2017). Accordingly, a bullock is a bovine intact male younger than 30 mo. of age by dentition or by verified (chronological) age and its carcass must be in the “A” maturity range (USDA, 2017). Additionally, these bullock carcasses exhibited a thin backfat thickness (mean value of 1.44 mm). It is noteworthy that the mean back-fat thickness of carcasses in the present crossbreeding trial did not vary significantly with breed type and the corresponding mean values ranged between 1.12 mm (F1-Chianina) to 1.91mm (Purebred Brahman) (Riera-Sigala et al., 2021). That purebred B. indicus types (Brahman) tend to exhibit thicker backfat thickness and/or more abundant (desirable) finish score than their B. taurus x B. indicus crossbred counterparts has been reported in previous works carried out under similar pasture-finish conditions (e.g., Barros Moreira et al., 2003; Jerez-Timaure and Huerta-Leidenz, 2009; Huerta-Leidenz et al., 2020).

Lean carcasses from grass-fed bulls with less than 3.5 mm-thick backfat have been amply documented in the American tropics (Huerta-Leidenz et al., 2004; Jerez-Timaure and Huerta-Leidenz, 2009; Rodríguez et al., 2014, Jerez-Timaure et al., 2015; Anaruma et al., 2020; Huerta-Leidenz et al., 2021; Torrecilhas et al., 2021). Dolezal et al. (1982) reported that beef carcasses with 2.54 mm of fat cover were rated the lowest ($P < 0.05$) for myofibrillar tenderness and had the highest ($P < 0.05$) WBSF values. Sensory quality increased as fat thickness increased up to 7.61 mm (Dolezal et al., 1982). Thus, the extreme leanness is an important reason why these young bulls may have a high propensity to cold shortening and subsequent meat toughness, as suggested by Seideman et al. (2007). In fact, Pflanzer et al. (2019) found shorter sarcomere lengths in gluteus medius (GM) of F1 Angus x Nellore bullocks (ca. 13 mo. of age and 440 kg live weight) that had been raised on a feedlot for 107 d and subjected to both delayed chilling and control (conventional chilling), indicating the suffering of cold shortening. According to the early work of Jeremiah (1996) in Canada, a minimum constraint of 8.0 mm of a subcutaneous fat thickness (in Continental B. taurus crossbred carcasses) should provide 90 % of consumer acceptability based on palatability without the need for postmortem technologies.

Among several antemortem factors, the genetic background notably affects the variation of most meat quality traits (Warner et al., 2010). It is well known that steers with a heavy influence of Bos indicus under feedlot-finishing in Australia (Schutt et al., 2009), Brazil (Pereira et al., 2015), and North America (Wright et al., 2018) are more likely to produce tougher meat. It has been noted that as the proportion of Brahman genetics increases, the sensory panel scores of loin steak tenderness, connective tissue, and juiciness decrease (Phelps et al., 2017; Wright et al., 2018). Genetic groups with increasing Brahman percentage have exhibited greater postmortem calpastatin content at 24-h postmortem and a concomitant reduction in calpain-1 autolysis and activity (Wright et al., 2018); hence, meat from cattle with a greater percentage of Brahman genetics has shown impaired proteolysis (reduced degradation of troponin-T, desmin, and titin) which is probably the reflection of a greater calpastatin activity (Wright et al., 2018).

Regarding meat quality, the sensory ratings for loin steaks of this bull sample varied little with breed type. The lack of significant variation in WBSF due to breed type and the very similar sensorial performance of the purebred Brahman to most F1 B. taurus was unexpected because, under pasture finishing, relevant effects of heterosis on textural quality of bull meat under grass-feeding conditions had been reported by Gama et al. (2013). In the latter study, steaks from pasture-finished crossbred commercial bulls (between 26 and 40 mo. of age) showed a considerable reduction in WBSF (26 % of the purebred mean at 24 h and 18 % after 10 d of aging). There are few scientific reports comparing bull meat quality traits of purebred B. indicus vs. B. taurus x B. indicus crossbreds produced under extensive (only grass-feeding) or semi-extensive (supplementation on pasture) tropical conditions. Comparable sensory ratings (all score means below 3.5 on a 1-8 identical descriptive scale) had previously been found among six breed types (Purebred Brahman, F1 Gelvieh, F1 Romosinuano, F1 Limousin, F1 Angus, and 3⁄4 Bos taurus) of young bulls supplemented on pasture at the same ranch (Jerez-Timaure and Huerta-Leidenz, 2009).

In some instances, the result from sensory evaluations contradicts those from WBSF measurements. Huerta-Leidenz et al. (1997) in a preliminary, non-controlled observational study conducted in Venezuela, had reported that steaks from harvest cattle classified as Zebu type (predominantly Brahman) were significantly rated as less tender, with a greater amount of connective tissue than other B.

taurus-influenced cattle. However, steaks from the Zebu type exhibited significantly lower WBSF values than those derived from the B. taurus-influenced types (Huerta-Leidenz et al., 1997). Contrarily, a study comparing Brahman and/or Charolais crosses with Thai native cattle (Asian B. indicus) reported that Charolais x Thai bulls exhibited lower WBSF values than Brahman x Thai bulls although both genotypes were analogous in sensory traits (Waritthitham et al., 2010). Also, it seems that the B. taurus or B. indicus type used in crossbreeding experiments affects the outcome in terms of eating quality response because Diniz et al. (2016) found that steaks from F1 Guzerat × Holstein crosses presented lower WBSF values than F1 Guzerat × Nellore and 1/2 Simmental x 1/4 Guzerat x 1/4 Nellore. Leal-Gutiérrez et al. (2018) classified steers into six different groups based on Angus composition (from 100 to 0% blood Angus). These authors found that cattle with more than 80 % Angus composition presented lower WBSF than animals with ≤ 60 % Angus composition; however, animals between 62 to 79 % Angus blood presented intermediate values. The results of our crossbreeding trial showed a similar trend to the findings of Leal-Gutierrez et al. (2018) because the group with 50 % Angus (F1ANG) trended to exhibit a lower mean WBSF value than the 100 % Brahman; however, the magnitude of such difference did not reach statistical significance. The introduction of heat-tolerant B. taurus breeds such as Senepol has been proposed as an alternative to improve the quality of beef in Tropical America. However, Jerez-Timaure et al. (2015) found no differences in WBSF when comparing young bulls from three Senepol x Brahman crosses (½ Senepol-½ Brahman; ¾ Senepol-¼ Brahman and ⅞ Senepol-⅛ Brahman). The latter experience indicates that when bulls are fed on pasture, despite their relatively young age (< 30 mo.) and irrespective of the proportion of the B. taurus (Senepol) genetics, the meat toughness is difficult to alleviate.

Effects of postmortem treatments

The ES is a widely used technology in the beef industry to mitigate cold- shortening-induced meat toughness by accelerating the glycolysis rate and the onset of rigor mortis while reducing the calpastatin activity which accelerates proteolysis (Ferguson et al., 2000; Savell et al., 2005, Li et al., 2012; Adeyemi and Sazili, 2014; Sami et al., 2015). In fact, ES has improved tenderness of the longissimus muscle from carcasses with strong Bos indicus influence (Ferguson et al., 2000). The application of ES alone or in combination with blade tenderization in Bos indicus-influenced cattle has been reported by Huerta-Leidenz et al. (1997). In the latter report, ES resulted as the most effective individual method for improving the meat quality of bulls (Huerta-Leidenz et al., 1997). Nevertheless, in the present study, ES was less effective than AGING in tenderizing bullocks' loins. The discrepancy of different reports about the effectiveness of ES in improving beef tenderness could be due to diverging technological parameters (frequency, voltage, stimulation duration, time of application) used by researchers; hence, the ES effectiveness varies from minimal to dramatic (Gursansky, 2010).

Individually considered, vacuum aging was more efficacious than ES at improving loin tenderness in the present study. Other promising tenderization results with the use of vacuum aging have been documented in beef from cattle finished on pasture or grain in tropical areas (Huerta-Leidenz et al., 2004; Rodas-González et al., 2007; Vilella et al., 2019). Steaks from Senepol x Nellore young bulls, vacuum aged for 7 or 14 days, exhibited significantly lower WBSF values and higher ratings in flavor intensity, amount of connective tissue, and fiber tenderness than non-aged samples (Huerta-Leidenz et al., 2004). In the latter study, the vacuum aging treatment increased the proportion of tender loin steaks from 42.9 % (aged for 2 d) to 71.4 % (aged for 14 d). According to Sami et al. (2015) to effectively tenderize longissimus muscles (i.e., by reaching a WBSF < 43.0 N) the vacuum aging period had to last at least 21 d. In fact, Vilella et al. (2019) reported that 28 d-vacuum-aged samples resulted in lower WBSF values than those from the control group, and 87 % of the aged steaks were classified as tender (WBSF < 40.1 N).

The most effective postmortem treatment in the present experiment was the ES+AGING because 72 % of the steaks were classified as tender (WBSF values < 4.09 kg; $P < 0.05$), which was 48 % superior to the control 2d-aged steaks. In previous studies, the significant differences in WBSF values between B. indicus and B. taurus breeds disappeared after applying ES+AGING. Ferguson et al. (2000) reported that WBSF values for ES-treated steaks derived from 100% B. indicus reached similar values to ES-treated steaks from 100% B. taurus counterparts at 7 d of aging.

When compared to the control samples, ES+AGING treated loins from BRAH, F1CHI, F1SIM, and F1ROM had a marked increase in tender steaks, which was not the case for the F1ANG counterparts. This finding supports previous observations (Huerta-Leidenz et al., 2004), showing that postmortem technologies caused relatively greater improvements in meat quality when applied to tougher meats than to those deemed as inherently tender.

In conclusion, the tenderness of loins derived from young bulls supplemented on pasture is marginally improved by crossbreeding; however, Angus genetics may be more suitable for that purpose than other B. taurus breeds under study. Further research with larger sample size is needed to characterize the effects of breed type. Individually, ES or vacuum aging technologies may mitigate tenderness problems of loins from young bulls; however, the combination of ES and vacuum aging was the best strategy to improve tenderness ratings and ensure a higher proportion of tender steaks.

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Literature Cited

Adeyemi, K. D., A. Q. Sazili. 2014. Efficacy of carcass electrical stimulation in meat quality enhancement: A review. Asian-Australasian Journal of Animal Science, 27: 447-456. https://doi.org/10.5713/ajas.2013.13463

AMSA. 2016. Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat. American Meat Science Association Educational Foundation. 105pp.

Anaruma, R. J., L. G. Reis, P. E. de Felício, S. B. Pflanzer, S. Rossi, M. A. Zanetti, N. R. B. Cónsolo, S. L. Silva, A. Saran Netto. 2020. Castration age and growth, meat production, and meat quality of Nellore male cattle. Animal Production Science, 60: 725–731 https://doi.org/10.1071/AN18460

Barros Moreira, F. B., N. E. Souza, M. Matsushita, I. N. Prado, and W. G. Nascimento. 2003. Evaluation of carcass characteristics and meat chemical composition of Bos indicus x Bos taurus crossbred steers finished in pasture systems. Brazilian Archives of Biology and Technology, 46: 609-616. https://doi.org/10.1590/S1516-

COVENIN. 1983. Comisión Venezolana de Normas Industriales. Norma venezolana 2072-83. Ganado bovino. Inspección Postmortem. p.10. Caracas, Venezuela.

Decreto Presidencial No. 1896. 1997. Gaceta Oficial de la República de Venezuela No 36.242. Venezuela República Bolivariana. p. 4. Caracas, Venezuela.

Diniz, F. B., S. D. J. Villela, M. H. F. Mourthé, P. V. R. Paulino, C. A. Boari, J. S. Ribeiro, J. A. Barroso, A. V. Pires, P. G. M. A. Martins. 2016. Evaluation of carcass traits and meat characteristics of Guzerat-crossbred bulls. Meat Science, 112:58-62. https://doi.org/10.1016/j.meatsci.2015.10.014

Dolezal, H. G., G. C. Smith, J. W. Savell, Z. L. Carpenter. 1982. Comparison of subcutaneous fat thickness, marbling, and quality grade for predicting palatability of beef. Journal of Food Science, 47: 397-401.

Ferguson, D. M., S. T. Jiang, H. Hearnshaw, S.R. Rymill, J.M. Thompson. 2000. Effect of electrical stimulation on protease activity and tenderness of M. longissimus from cattle with different proportions of Bos indicus content. Meat Science, 55:265-272. https://doi.org/10.1016/S0309-1740(99)00131-X

Fondo Nacional de Ciencia, Tecnología e Innovación (MCT-FONACIT). 2002. Código de Bioética y Bioseguridad, 2nd ed.; Ministerio del Poder Popular para Ciencia, Tecnología e Industrias Intermedias y el Fondo Nacional de Ciencia, Tecnología e Innovación: Caracas, Venezuela, pp. 1–35. Available online: https://cupdf.com/download/bioetica-fonacit (accessed on 10 March 2020).

Gama, L. T., M. C. Bressan, E. C. Rodrigues, L. V. Rossato, O. C. Moreira, S. P. Alves, R. J. B. Bessa. 2013. Heterosis for meat quality and fatty acid profiles in crosses among Bos indicus and Bos taurus finished on pasture or grain. Meat Science, 93: 98-104. https://doi.org/10.1016/j.meatsci.2012.08.005

Gursansky, B., J. M. O'Halloran, A. Egan, C. E. Devine. 2010. Tenderness enhancement of beef from Bos indicus and Bos taurus cattle following electrical stimulation. Meat Science, 86: 635-641. https://doi.org/10.1016/j.meatsci.2010.05.002

Huerta-Leidenz, N., N. Jerez-Timaure, A. Rodas-González, E. Márquez, M. Arispe, J. M. Rivero. 1997. Preliminary observations on the use of postmortem technologies to improve quality of beef derived from Venezuelan cattle differing in breed type, sex condition, and age. Revista Científica FCV-LUZ, 7:123-132. https://www.produccioncientificaluz.org/index.php/cientifica/article/view/14284

Huerta-Leidenz, N., N. Jerez-Timaure, O. Morón-Fuenmayor, E. R. Urdaneta, R. Caro. 1996. Experiences during training of a descriptive taste panel at a packing house of Venezuela. Archivos Latinoamericanos de Nutrición, 46:47-53. https://www.alanrevista.org/ediciones/1996/1/art-10/

Huerta-Leidenz, N., A. Rodas-González, G. C. Smith. 2004. Effect of vacuum aging and influence of sire on palatability of beef longissimus from grass-fed F1 Senepol x Zebu bulls. Revista Científica FCV-LUZ, 14:1-14. https://www.produccioncientificaluz.org/index.php/cientifica/article/view/15053

Huerta-Leidenz, N., A. Ruiz-Flores, J. Valerio-Hernández, N. Jerez-Timaure, A. Rodas-González. 2020. Bullock carcass performance trends in Brahman and F1 crosses fattened on tropical pastures. NACAMEH, 14: 16–30. https://www.doi.org/10.24275/uam/izt/dcbs/nacameh/2020v14n1/Huerta

Huerta-Leidenz, N., N. Jerez-Timaure, S. Godoy, C. Rodríguez-Matos, O. Araujo-Febres. 2021. Fattening performance and carcass traits of implanted and supplemented grass-fed bulls. Revista Científica FCV-LUZ, 31 (2): 53-60. https://www.produccioncientificaluz.org/index.php/cientifica/article/view/36161

Jeremiah, L. E. 1996. The influence of subcutaneous fat thickness and marbling in beef. Food Research International, 29: 513-520. https://doi.org/10.1016/S0963-9969(96)00049-X

Jerez-Timaure, N., G., Martínez, M., González. 2015. Commercial value of beef carcass and meat from Senepol x Brahman bulls in Venezuela. Revista Científica FCV-LUZ, 25(6):462-470.

Jerez-Timaure, N., N. Huerta-Leidenz. 2009. Effects of breed type and supplementation during grazing on carcass traits and meat quality of bulls fattened on improved savannah. Livestock Science, 121:219-226. https://doi.org/10.1016/j.livsci.2008.06.015

Leal-Gutiérrez, J. D., M. A. Elzo, D. D. Johnson, T. L. Scheffler, J. M. Scheffler, R. G. Mateescu. 2018. Association of μ-calpain and calpastatin polymorphisms with meat tenderness in a Brahman-Angus population. Frontiers in Genetics, 9: 1-10. https://doi.org/10.3389/fgene.2018.00056

Li, C. B., J. Li, G. H. Zhou, R. Lametsch, P. Ertbjerg, D. A. Bruggemann, H. G. Huang, A. H. Karlsson, M. Hviid, K. Lundstrom. 2012. Electrical stimulation affects metabolic enzyme phosphorylation, protease activation, and meat tenderization in beef. Journal of Animal Science, 90: 1638−1649. https://doi.org/10.2527/jas.2011-4514

Montero, A., N. Huerta-Leidenz, A. Rodas-González, L. L. Arenas de Moreno. 2014. Fabrication, and variation of the cut-out yield of beef carcasses in Venezuela: Anatomical description of the process and equivalency of cut nomenclature to North American counterparts. NACAMEH, 8:1-22. http://www.doi.org/10.24275/uam/izt/dcbs/nacameh/2014v8n1/Montero

Nair, M. N., A. C. V. C. S. Canto, G. Rentfrow, S. P. Suman. 2019. Muscle-specific effect of aging on beef tenderness. LWT, 100:250-252. https://doi.org/10.1016/j.lwt.2018.10.038

Pereira, A. S. C., F. Baldi, R. D. Sainz, B. L. Utembergue, H. L. J. Chiaia, C. U. Magnabosco, F. R. Manicardi, F. R. C. Araujo, C. F. Guedes, R. C. Margarido, P. R. Leme, P. J. A. Sobral. 2015. Growth performance, and carcass and meat quality traits in progeny of Poll Nellore, Angus, and Brahman sires under tropical conditions. Animal Production Science, 55:1295-1302. https://doi.org/10.1071/AN13505

Pflanzer, S. B., C. L. Gomes, P. E. de Felicio. 2019. Delayed carcass chilling improves tenderness of the beef gluteus medius muscle. Pesquisa Agropecuaria Brasileira, v.54, e00099. https://doi.org/10.1590/S1678-3921.pab2019.v54.00099.

Phelps, K. J., D. D. Johnson, M. A. Elzo, C. B. Paulk, J. M. Gonzalez. 2017. Effect of Brahman genetics on myofibrillar protein degradation, collagen crosslinking, and tenderness of the longissimus lumborum. Journal of Animal Science, 95:5397-5406. https://doi.org/10.2527/jas2017.2022

Riera-Sigala, T., N. Huerta-Leidenz, N. Jerez-Timaure, A. Rodas-González, J. Ordoñez-Vela, A. Moya. 2021. Preliminary observations on carcass traits and meat yield of five types of Brahman-influenced grass-fed bulls. Archivos Latinoamericanos de Producción Animal, 29(1-2): 67-78. https://doi.org/10.53588/alpa.291208

Riera-Sigala, T., A. Rodas-González, C. Rodríguez-Matos, J. Avellaneda-Barbarito, N. Huerta-Leidenz. 2004. Rasgos de crecimiento y pesos en canal de toros Brahman puros y F1 Brahman x Bos taurus criados y cebados semi-intensivamente en sabana mejorada. Archivos Latinoamericanos de Producción Animal, 12: 66-72. https://ojs.alpa.uy/index.php/ojs_files/article/view/19

Riley, D. G., C. C. Chase Jr., S. W. Coleman, W. A. Phillips, M. F. Miller, J. C. Brooks, D. D. Johnson, T. A. Olson. 2012. Genetic effects on carcass quantity, quality, and palatability traits in straightbred and crossbred Romosinuano steers. Journal of Animal Science, 90(7):2159. https://doi.org/10.2527/jas.2011-4471

Rodas-González, A., J. Vergara-López, L. Arenas de Moreno, N. Huerta-Leidenz, M. Leal, M. F. Pirela. 2007. Effect of supplementation regimes and vacuum ageing on palatability of beef longissimus from Criollo Limonero steers fattened on pasture. Revista Científica FCV-LUZ, 17:1-8.

Rodas-González, A., N. Huerta-Leidenz, N. Jerez-Timaure, M. F. Miller. 2009. Establishing tenderness thresholds of Venezuelan beef steaks using consumer and trained sensory panels. Meat Science, 83:218-223. https://doi.org/10.1016/j.meatsci.2009.04.021

Rodríguez, J., J. Unruh, M. Villarreal, O. Murillo, S. Rojas, J. Camacho, J. Reinhardt, C. 2014. Carcass and meat quality characteristics of Brahman cross bulls and steers finished on tropical pastures in Costa Rica. Meat Science, 96, 1340-1344. https://doi.org/10.1016/j.meatsci.2013.10.024

Sami, A., E. Mills, J. F. Hocquette. 2015. Relationships between DNAJA1 expression and beef tenderness: Effects of electrical stimulation and postmortem aging in two muscles. International Journal of Agricultural Biology, 17:815-820. doi:10.17957/IJAB/14.0024

SAS. SAS/STAT User´s Guide. (Release 9.4). Cary, NC, USA: SAS Institute, Inc.; 2012.

Savell, J.W., S.L. Mueller, B.E. Baird. 2005. The chilling of carcasses. Meat Science, 70: 449-459. https://doi.org/10.1016/j.meatsci.2004.06.027

Schutt, K. M., H. M. Burrow, J. M. Thompson, B. M. Bindon. 2009. Brahman and Brahman crossbred cattle growth on pasture and in feedlots in subtropical and temperate Australia. 2. Meat quality and palatability. Animal Production Science, 49: 452-460. https://doi.org/10.1071/EA08082

Seideman, S. C., H. R. Cross, L. D. Crouse. 2007. Variations in the sensory properties of beef as affected by sex condition, muscle, and postmortem aging. Journal of Food Quality, 12(1): 39-58. https://digitalcommons.unl.edu/hruskareports/66/

Torrecilhas, J. A., E. San Vito, G. Fiorentini, P. de Souza Castagnino, T. A. Simioni, J. F. Lage, T. T. Berchielli. 2021. Effects of supplementation strategies during the growing phase on meat quality of beef cattle finished in different systems. Livestock Science, 247:104465. https://doi.org/10.1016/j.livsci.2021.104465

USDA. 2017. Official United States Standards for Grades of Carcass Beef. Washington, DC. United States Department of Agriculture, Agricultural Marketing Service.

Vilella, G. F., C. L. Gomes, C. T. Battaglia, M. T. B. Pacheco, V. S. N. da Silva, A. Rodas-González, S. B. Pflanzer. 2019. Effects of combined wet-and dry-aging techniques on the physicochemical and sensory attributes of beef ribeye steaks from grain-fed crossbred zebu steers. Canadian Journal of Animal Science, 99(3):497-504. https://doi.org/10.1139/cjas-2018-0127

Waritthitham, A., C. Lambertz, H. J. Langholz, M. Wicke, M. Gauly. 2010. Assessment of beef production from Brahman × Thai native and Charolais × Thai native crossbred bulls slaughtered at different weights. II: Meat quality. Meat Science, 85(1):196-200. https://doi.org/10.1016/j.meatsci.2009.12.025

Warner, R.D., P.L. Greenwood, D.W. Pethick, D.M. Ferguson. 2010. Genetic and environmental effects on meat quality. Meat Science, 86:171-183. https://doi.org/10.1016/j.meatsci.2010.04.042

Wright, S. A., P. Ramos, D. D. Johnson, J. M. Scheffler, M. A. Elzo, R. G. Mateescu, A. L. Bassa, C. C. Carra, T. L. Schefflera. 2018. Brahman genetics influence muscle fiber properties, protein degradation, and tenderness in an Angus-Brahman multi-breed herd. Meat Science, 135:84-93. https://doi.org/10.1016/j.meatsci.2017.09.006