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Carcass characteristics and sensorial evaluation of meat from Nellore steers and crossbred Angus vs. Nellore bulls

Vinicius Cunha Barcellos[1], Camila Mottin[2], Rodrigo Augusto Cortez Passetti[2*], Ana Guerrero[3], Carlos Emanuel Eiras[4], Paulo Emílio Prohman[5], Ana Carolina Pelaes Vital[1] and Ivanor Nunes do Prado[1, 2]

*[1]Programa de Pós-graduação em Ciência de Alimentos, Universidade Estadual de Maringá, Av. Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. [2]Departamento de Ciências Biológicas, Universidade Estadual de Maringá, Maringá, Paraná, Brazil. [3]Departamento de Produção Animal e Ciência de Alimentos, Universidade de Zaragoza, Zaragoza, Espanha. [4]Centro Universitário AGES, Paripiranga, Bahia, Brazil. [5]Maria Macia Cooperativa, Campo Mourão, Paraná, Brazil. *Author for correspondence. E-mail: racpassetti@gmail.com*

ABSTRACT. This study evaluated animal performance, carcass characteristics and meat quality of 36-month old Nellore steers finished in pastures (n = 10) and 20-month old Angus *vs.* Nellore bulls finished in feedlot (n = 10). Final body weight, carcass weight, characteristics, conformation and fat thickness, were higher ($p < 0.001$) for the Nellore steers than for Angus *vs.* Nellore bulls. Water losses during chilling (24 hours, 4ºC) were lower ($p < 0.05$) for Nellore steers than for the Angus *vs.* Nellore bulls. Muscle percentage on the 6th rib was higher ($p < 0.05$) for the Nellore steers than for Angus *vs.* Nellore bulls; while bone percentage was lower ($p < 0.05$) for Nellore steers. After 7 and 14 days of ageing, the L★ meat value was higher for the Nellore steers than for the Angus *vs.* Nellore bulls; the L★ meat value was similar ($p > 0.05$) throughout the ageing period for the Angus *vs.* Nellore bulls, but higher in meat from the Nellore steers ($p < 0.05$). Genetic group had no effect ($p > 0.05$) on meat a★ value (redness). Likewise, ageing time had no effect on a★ in both genetic groups, and genetic group had no effect ($p > 0.05$) on meat b★ value (yellowness). On the other hand, b★ was increased after day 7 of ageing for the bulls from the two genetic groups. Thawing and cooking losses were lower for Nellore steers after day 7 of aging ($p < 0.05$). The meat of the Angus *vs.* Nellore bulls was more tender ($p < 0.05$) at all ageing times studied (1, 4, 7 and 14 days) than the meat of the Nellore steers. Genetic group had no effect ($p > 0.05$) on lipid oxidation; however, lipid oxidation increased after day7. Meat from Nellore steers contained a higher percentage of saturated fatty acids (SFA), a lower percentage of unsaturated (UFA) and monounsaturated fatty acids (MUFA) and a similar percentage of polyunsaturated fatty acids (PUFA) than the meat from Angus *vs.* Nellore bulls. Intramuscular fat from Nellore steers had a more favourable n-6:n-3 fatty acid ratio than that from Angus *vs.* Nellore bulls (4.37 *vs.* 11.45, respectively). Tenderness, flavour and overall acceptability were higher ($p < 0.001$) for meats of the Nellore steers, regardless of ageing time (1, 4, 7 and 14 days).

Keywords: Brazil, consumer acceptability, fattening system, genetic groups, meat quality, sexual class.

Características de carcaça e avaliação sensorial da carne de novilhos Nelore e touros cruzados Angus vs. Nelore

RESUMO. Este estudo foi realizado para avaliar o desempenho animal, características de carcaça e qualidade da carne de novilhos Nelore terminados em pastagens e abatidos aos 36 meses de idade (n = 10) e machos não castrados Angus *vs.* Nelores abatidos aos 20 meses de idade (n = 10). O peso final, peso, características e conformação da carcaça e espessura de gordura de cobertura foram maiores ($p < 0,001$) para os novilhos Nelores do que para os mestiços Angus *vs.* Nelores. As perdas de água durante o resfriamento (24 horas, 4º C) foram menores ($p < 0,05$) para os novilhos Nelores do que para os mestiços Angus *vs.* Nelores. A percentagem de músculo na 6ª costela foi maior ($p < 0,05$) para os novilhos Nelores do que para os mestiços Angus *vs.* Nelores; enquanto que a percentagem de osso foi menor ($p < 0,05$) para os novilhos Nelores. Após 7 e 14 dias de maturação, o valor de L★ da carne foi maior ($p < 0,05$) para os novilhos Nelores do que para os mestiços Angus *vs.* Nelores. O valor de L★ foi similar ($p > 0,05$) ao longo da maturação para os mestiços Angus *vs.* Nelores; enquanto que o valor de L★ da carne dos novilhos Nelores aumentou ($p < 0,05$). O grupo genético não teve efeito ($p > 0,05$) sobre o valor de a★ (cor vermelha). Da mesma forma, o tempo de maturação não teve efeito ($p > 0,05$) para os animais dos dois grupos genéticos. O grupo genético não teve efeito ($p > 0,05$) sobre o valor de b★ (cor amarela). Por outro lado, o tempo de maturação aumentou o valor de b★ após o sétimo dia para os animais dos dois grupos genéticos. A perda por descongelamento e cocção foi menor ($p < 0,05$) para os novilhos Nelores após o

sétimo dia de maturação. A carne dos mestiços Angus *vs.* Nelores foi mais macia ($p < 0,05$) em todos os tempos de maturação (1, 4, 7 e 14 dias) do que a carne dos novilhos Nelores. O grupo genético não teve efeito ($p > 0,05$) sobre a oxidação de lipídeos; no entanto, a oxidação de lipídeos aumentou após o sétimo dia. A carne dos novilhos Nelores continha maior percentagem de ácidos graxos saturados (AGS), menor percentagem de ácidos graxos não saturados (AGNS) e monoinsaturados (AGMI) e similar percentagem de ácidos graxos poli-insaturados (AGPI) do que a carne dos mestiços Angus *vs.* Nelores. A gordura intramuscular dos Nelores tinha melhor razão n-6:n-3 do que a carne dos mestiços Angus *vs.* Nelores (4,37 vs. 11,45, respectivamente. A maciez, aroma e aceitabilidade geral foram maiores ($p < 0,001$) para a carne dos novilhos Nelores, desconsiderando o tempo de maturação (1, 4, 7 e 14 dias).

Palavras-chave: Brasil, consumidor, sistema de acabamento, grupo genético, qualidade da carne, classe sexual.

Introduction

In Brazil, traditional cattle production is extensive and usually pasture-based (Ferraz & Felício, 2010). Zebu breeds (*Bos taurus indicus*), such as Nellore, are frequently used (Moreira et al., 2008; Rotta et al., 2009; Silva et al., 2010). However, this production system is characterised by a low efficiency, with an average carcass weight of around 225 kg at 36 months slaughter age and a potential negative impact on the meat quality (Prado et al., 2012; Rotta et al., 2009). However, the production costs are generally lower than those of intensive systems (El-Memari et al., 2003; Silva et al., 2010).

In Brazil, cattle production systems based on pastures are mainly located in the central-western, northern and north-eastern regions of the country (Ferraz & Felício, 2010). In the south-eastern and southern regions, a relative percentage of the cattle are finished in feedlots due to the high grain production in these regions. However, Zebu cattle finished in feedlots are less interesting for the consumer market than crossbred cattle (Zebu and Europeans) due to their lower feed efficiency. In addition, crossbreeding among *Bos taurus taurus* and *Bos taurus indicus* significantly reduces slaughter age and improves feed efficiency and meat quality.

This study evaluated animal performance, carcass characteristics and meat quality of 36-month old Nellore steers finished in pastures and 20-month old Angus *vs.* Nellore bulls.

Material and methods

Ethics committee and locality

The experiment was conducted in Campo Mourão City, Paraná State, and south Brazil. All procedures have been approved by the Department of Animal Production and the Research Ethic Committee of the State University of Maringá, following the principles of biomedical research with animals, nº 081/2014 (CIOMS, 1985).

Animals and finishing system

We used a total of 20 animals; 10 Nellore steers with a body weight of 580 kg and 10 crossbred bulls (½ Angus *vs.* ½ Nellore) with a body weight of 470 kg, in a completely randomised experimental design. The Nellore steers were finished in a conventional system, *Brachiaria brizantha* pasture in Paraná State, south Brazil. Angus *vs.* Nellore bulls were finished in a feedlot system commonly used in Brazil, fed with corn silage (40% DM) and concentrate (60% corn cracked grain, soy bean meal, urea and mineral salt).

Slaughtering and carcass characteristics

The animals were transported to a commercial slaughterhouse (Campo Mourão city, Paraná, south Brazil). Truck stocking density was 0.8 ± 0.2 animal m^{-2} and transport distance less than 80 km. According to the common practices of the Brazilian beef industry, the animals were stunned using a captive-bolt pistol. Carcasses were not subjected to electrical stimulation. Afterwards, the carcasses were medially divided, washed, labelled and stored in a cold chamber at 4ºC, where they remained for a 24-h period.

Twenty-four hours later, cold carcass weight was determined. Cold carcass dressing percentage was calculated using the cold carcass weight: body weight ratio. Chilling loss percentage was defined as hot carcass weight minus cold carcass weight, divided by hot carcass weight and multiplied by 100. Carcass length was measured from the skull board to the pubis bone on the anterior side of the first rib. Leg length was evaluated with a wooden compass with metallic edges that measured the distance from the anterior border of the pubis bone to a middle point on the tarsus bone. Cushion thickness was determined with a wooden compass with metallic edges that measured the distance between the lateral face and the median at the superior part of the cushion. For carcass conformation, a point scale was used; on this scale, the highest value indicates the best conformation. The conformation was reported as superior, very good, good, regular, poor or inferior; ratings could also be reported as plus, mid and minus. Carcass muscle (MP), fat (FP), bone

(BP) and others were physically separated from the *Longissimus* section, which corresponds to the 6th rib, and individually weighed according to Robelin and Geay (1975).

Sampling and meat characteristics

Longissimus muscle (LM) samples (6th to 13th rib) were identified, removed and stored in vacuum bags (polyamide/polyethylene pouches of 120 μm and 1 cm^3 m^{-2} $24h^{-1}$ 0_2 permeability, 3 cm^3 m^{-2} $24h^{-1}$ CO_2 permeability measured at 5°C and 75% relative humidity; water vapor transmission rate (WVTR) 3 g m^{-2} $24h^{-1}$ at 38°C and 100% RH; the vicat softening point of sealing was reached at 97°C and had a dart drop strength of 1,300 g), then immediately transported to the Laboratory of Technology and Production of Animal Origin of the Animal Science Department at the State University of Maringá. Two-cm thick steaks were cut, vacuum-packaged (99% vacuum, with a Sulpack SVC 620 machine) and aged for one day before being frozen and stored at −18°C for further analysis.

The pH was measured in the muscle between the 12th and 13th ribs. Fat thickness was measured with a caliper, averaging three points between the 12th and the 13th ribs. Marbling was measured on the LM from the 12th rib, using the Brazilian scoring system (18 to 16 – abundant, 15 to 13 – moderate, 12 to 10 – mean, 9 to 7 – small, 6 to 4 – light and 3 to 1 – traces). The LM area was measured with a tracing made on the 12th and 13th ribs. Subsequently, a compensating planimeter was used to determine the area.

Meat colour in the CIELAB space was assessed in fresh meat before the steaks were frozen by using a Minolta CR-400 spectrophotometer (Konica, Minolta Holdings, Osaka, Japan) with a 10° view angle and a D65 illuminant at 30 min after blooming.

To estimate thawing losses, steaks were thawed over the course of 24 h under refrigeration conditions (4°C) and subsequently weighed; thawing losses were calculated as the percentage difference between the fresh and thawed weights. For determination of cooking losses, the steaks were weighed and wrapped in aluminium film. Each sample was cooked in a pre-heated grill at 200°C until reaching an internal temperature of 55°C, which was monitored with a penetration thermocouple. Afterwards, the sample was removed from the grill and chilled at ambient temperature. Once it reached 20°C, each steak was weighed in order to calculate the cooking loss as the difference in weight before and after cooking.

For texture analysis, the same cooked steaks were analysed by using a texture analyser Stable Micro Systems TAXT Plus (Texture Technologies 15 Corp., UK) with a Warner-Bratzler cell, while following the principles proposed by Honikel (1998). The meat was cut into rectangular pieces of 1 cm^2 cross-sections, perpendicular to the direction of the muscle fibres.

Lipid oxidation was quantified using the Thiobarbituric Acid Reactive Substances (TBARS) method following Pfalzgraf, Frigg and Steinhart (1995). Values were expressed as mg of malonaldehyde (MDA) per kg of raw meat.

The chemical composition (percentages of water, ash, crude protein, total lipids and total collagen) was determined by near infrared transmittance, using a Food Scan Lab TM (Foss NIR Systems, Inc., USA) instrument, which operates in a transmittance mode from 850 to 1,050 nm at 2-nm intervals.

For fatty acids analysis, a specific portion of intramuscular fat from the sixth rib level was extracted with a chloroform/methanol mixture. Fatty acid methyl esters (FAMEs) were prepared using methylation and analysed through a gas chromatograph (Varian Medical Systems, Palo Alto, California, USA) equipped with a flame ionisation detector and CP-7420 Select Fame fused silica capillary column (100 m x 0.25 mm ID, 0.39 μm film thickness, Varian, USA). Column temperature was 165°C for 18 min, 180°C (30°C min^{-1}) for 22 min and 240°C (15°C min^{-1}) for 30 min with a 45-psi pressure. Injector and detector were both maintained at 220 and 245°C, respectively. Gas fluxes (White Martins, Rio de Janeiro, Brazil) comprised 1.4 mL min^{-1} for carrier gas (H_2), 30 mL min^{-1} for make-up gas (N_2) and 30 mL min^{-1} and 300 mL min^{-1} for H_2 and synthetic flame gas, respectively. Injection split mode was 1/80. Fatty acids were identified by comparing the relative retention time of the FAME peaks of the samples with the fatty acid methyl ester standards (Sigma, St. Louis, Missouri, USA) by spiking the samples with the standard. The peak areas were determined by the Star software (Varian, Walnut Creek, California, USA). Data are expressed as percentages for the normalised area of fatty acids.

Consumer sensory evaluation

Four steaks (2.5 cm thickness) were cut from LT between the 8th and 12th ribs from each animal. Steaks were vacuum-packed and aged for 1, 4, 7 and 14 days before being frozen at −18°C. They were thawed at 4°C for 24 h before analysis. Each steak was covered with aluminium foil codified with a random three-digit code and cooked in a pre-heated

grill (Philco Grill Jumbo Inox, Philco S.A., Joinville, Brazil) at 200°C until reaching an internal temperature of 70°C, monitored with a penetration thermocouple (Incoterm, 145 mm; Incoterm Ltda, Porto Alegre, Brazil). Each steak was cut into 10 x 2 × 2 cm cubes and kept warm (50°C) until consumer evaluation (< 10 min after cooking). The consumer test for beef quality perception was performed at a Supermarket, at Campo Mourão City, Brazil south, in a private room adequately adapted to perform consumer sensory tests.

All consumers were asked to taste the meat samples and evaluate three attributes: tenderness, flavour and overall acceptability; this was achieved using a structured hedonic nine-point scale ranging from 1 = dislike extremely to 9 = like extremely, where a medium level was not included, according to the methodologies described by Font-i-Furnols et al. (2008).

Statistical analysis

The experimental design was completely randomised with two genetic groups and 10 replicates. All studied characteristics were tested for normality (Shapiro-Wilk test). Those that showed a normal distribution were analysed via analysis of variance by using the procedure proc MIXED in the SAS statistical package (Statistical Analysis System, version 8.1), with animal identity as a random effect. The experimental genetic group effect was evaluated (Nellore and Angus *vs.* Nellore) for all variables and the effects of ageing period (1, 4, 7 and 14 days) on water holding capacity (WHC), lipid oxidation (TBARS) and Warner-Braztler Shear Force (WBSF) variables were evaluated. The interactions were also included in the model. For consumer analysis, the consumer was considered a random factor and the session a block effect. Differences between genetic group means were assessed by using Tukey's test ($p < 0.05$).

Results and Discussion

Carcass and meat characteristics

Final body weight was higher ($p < 0.001$) for the Nellore steers (578.4 kg) than for the crossbred Angus *vs.* Nellore bulls (470.8 kg; Table 1), which was a result of the different age at slaughter. The Nellore steers were slaughtered at 36 months; while Angus *vs.* Nellore bulls were slaughtered at 20 months. Similarly, cold carcass weight was higher ($p < 0.001$) for Nellore steers than for Angus *vs.* Nellore bulls. The correlation between final body weight and cold carcass weight was high ($r^2 = 0.999$; $p < 0.0001$). Carcass weight was high for Nellore steers and above the market recommendations in Brazil (225-250 kg), (Ferraz & Felício, 2010). However, the cattle finished in the pasture system need higher weights to meet the requirements of the Brazilian market (Rotta et al., 2009).

Table 1. Final boy weight, carcass and meat characteristics of the Nellore and Angus *vs.* Nellore bulls.

Parameters	Genetic groups		SEM*	P <
	Nel.	Ang. *vs.* Nel.		Value
Final weight, kg	578.4	470.8	16.14	0.001
Cold carcass weight, kg	314.0	258.9	8.47	0.001
Cold dressing carcass, %	54.28	55.00	0.09	0.001
Chilling loss, %	1.37	1.66	0.03	0.001
Carcass length, cm	131.8	141.4	1.69	0.002
Leg length, cm	82.1	82.8	0.53	0.529
Cushion thickness, cm	113.8	118.1	0.93	0.018
Conformation, points	17.82	10.26	0.29	0.001
Fattening, points	4.60	2.50	0.27	0.001
Muscle, %	65.0	59.2	0.87	0.001
Fat, %	17.87	18.87	0.68	0.484
Bone, %	11.05	17.73	0.91	0.001
Others, %	4.09	4.16	0.42	0.210
pH_{24h}	5.61	5.64	0.03	0.665
Fat thickness, mm	8.31	5.45	0.72	0.044
Marbling, points	5.82	5.12	0.15	0.105
Longissimus muscle, cm^2	50.6	45.4	2.66	0.343

*Standard error of mean.

Carcass dressing percentage was similar ($p < 0.10$) between Nellore and crossbred Nellore *vs.* Angus bulls. In general, in Brazil, carcass dressing percentage of Nellore or crossbred bulls can vary from 50 to 55% (Cruz et al., 2014; Rotta et al., 2009; Zawadzki et al., 2011).

Water loss during chilling (24 hours, 4°C) was lower ($p < 0.05$) for Nellore steers than for crossbred Angus *vs.* Nellore bulls (Table 1), which may be related to fat thickness. Nellore steers were heavier and had a higher fat thickness. Mean water loss value in the carcass during chilling was 1.5%. This value is considered acceptable for the beef market in Brazil (Françozo et al., 2013).

Carcass length was higher ($p < 0.002$) for crossbred Angus *vs.* Nellore bulls (141.4 cm) than for Nellore steers (131.8 cm). The greater carcass length for crossbred bulls can be explained by the effect of breed. European cattle have a higher carcass length when compared to Zebu cattle (Maggioni et al., 2010; Rotta et al., 2009). However, leg length was similar ($p > 0.05$) for the bulls from the two genetic groups. Cushion thickness was higher ($p < 0.05$) for Angus *vs.* Nellore bulls than for Nellore steers. In general, European cattle have a greater hindquarter and, consequently, a greater cushion thickness (Rotta et al., 2009). Carcass conformation and fattening was higher ($p < 0.001$) for Nellore steers than for crossbred bulls, which was correlated to the finishing degree of the cattle. Nellore steers were heavier and had a better yield grade.

Muscle percentage on the 7th rib was higher ($p < 0.001$) for Nellore steers than for Angus *vs.* Nellore bulls; while bone percentage was lower ($p < 0.001$) for Nellore steers. In general, carcasses from Zebu cattle presented smaller bone and more muscle percentages (Rotta et al., 2009). Fat percentage was similar ($p > 0.05$) between the two genetic groups, which may be due to slaughter age. Nellore steers were slaughtered at 36 months (older); while Angus *vs.* Nellore bulls were slaughtered at 20 months (younger).

The pH was similar ($p > 0.05$) between Nellore steers and Nellore *vs.* Angus bulls, with a mean pH of 5.6. A low pH values, as observed in this study, shows that the animals were not stressed at slaughter time (Guerrero et al., 2016; Rivaroli et al., 2016).

Fat thickness was higher ($p < 0.05$) for Nellore steers than for Angus *vs.* Nellore bulls. Fat thickness can be defined as excessive for Nellore steers (8.3) and good for Angus *vs.* Nellore bulls (5.5 mm). The domestic meat market in Brazil requires cattle carcasses to have a fat thickness between 3 and 6 mm in order to avoid penalties. However, carcasses intended for export must have a higher fat thickness (Ngapo, Riendeau, Laberge, & Fortin, 2013).

Genetic group had no effect ($p > 0.05$) on meat marbling (Table 1). The mean marbling was 5.4 points and classified as 'moderate' within the range of the Brazilian evaluation system. In general, European bulls or crossbred bulls between Europeans *vs.* Zebu breeds have greater meat marbling (Hocquette, 2010; Rotta et al., 2009). Thus, it could be expected that the crossed bulls between Angus *vs.* Nellore could have greater marbling; a fact that did, however, not occur. In addition to the genetic group, slaughter weight and finishing degree also have an effect on meat marbling (Ngapo et al., 2013). The Nellore steers were older and heavier and were therefore expected to have higher meat marbling.

The LM area was higher ($p < 0.05$) for Nellore steers than for the Angus *vs.* Nellore bulls, which was due to the higher carcass weight of these bulls.

Meat colour

At 24 hours, 4, 7 and 14 days of ageing, the L⋆ meat value (lightness) was similar ($p > 0.05$) in the meat from of the two genetic groups (Table 2). The L⋆ meat value was similar ($p > 0.05$) throughout the ageing period for Nellore steers, except for the seventh day, while L⋆ meat value for Angus *vs.* Nellore bulls increased significantly ($p < 0.05$). Nellore steers presented L⋆ meat value close to 39.1 points, while the L⋆ meat value of Angus *vs.* Nellore bulls increased from 37.6 to 41.9 points during the ageing period, characterising an evolution from a darker to a lighter meat. For meat from Nellore steers, the L⋆ value increased from day 1 to day 7 of the ageing period (37.1 to 41.6 points), a phenomenon that has been observed in beef steaks that were displayed under high levels of oxygen (Prado et al., 2015). Chemical changes in myoglobin did not influence L⋆ meat values (McKenna, Mies, Baird, Pfeiffer, Ellebracht et al., 2005), but the protein structures that changed with ageing due to proteolysis-influenced lightness (Renerre, 1981). During aging, the cells of the muscle structure lose the integrity of the cell walls, showing less water retention capacity. In an injured cell, the water exudes into the extracellular space and the light that is affected is almost completely reflected, which makes its coloration clearer (Huff-Lonergan & Lonergan, 2005).

Table 2. L⋆ (lightness), a⋆ (redness) and b⋆ (yellowness) of the meat aged for 1, 4, 7 and 14 days from Nellore steers and Angus *vs.* Nellore bulls.

Days	Genetic groups		SEM⋆	p < Value
	Nellore	Ang.x Nel.		
		L⋆		
1	37.07^{A}	37.59^{A}	0.44	0.573
4	39.12^{AB}	37.74^{A}	0.45	0.131
7	41.63^{B}	41.66^{B}	0.50	0.098
14	38.79^{A}	40.88^{B}	0.54	0.092
SEM	0.43	0.47		
p < Value	0.001	0.004		
		a⋆		
1	14.58^{A}	13.30^{A}	0.42	0.140
4	14.43^{A}	14.14^{A}	0.18	0.447
7	12.88^{B}	11.31^{B}	0.29	0.583
14	14.81^{A}	13.20^{A}	0.29	0.382
SEM	0.22	0.26		
p < Value	0.019	0.010		
		b⋆		
1	12.87^{A}	11.83^{A}	0.29	0.074
4	12.94^{A}	12.07^{A}	0.25	0.093
7	15.44^{B}	15.11^{B}	0.36	0.264
14	15.00^{B}	15.83^{B}	0.28	0.190
SEM	0.27	0.33		
p < Value	0.001	0.001		

A, B: different superscript letters represent significant differences within column, between ageing time ($p \leq 0.05$). ⋆Standard error of mean.

Genetic group had no effect ($p > 0.05$) on a⋆ meat value (redness). Likewise, with exception of day 7, the ageing time had no effect ($p > 0.05$) on a⋆ meat values for the bulls from both genetic groups. Similarly, genetic group had no effect ($p > 0.05$) on b⋆ meat value (yellowness). On the other hand, b⋆ meat value increased from day 7 for both genetic groups. This could be explained by the increase of brown pigments as a result of oxidation of oxymyoglobin to metmyoglobin (Mancini & Hunt, 2005).

Water holding capacity

Before and four days after the beginning of the ageing period, thawing water losses were similar

($p > 0.05$) in the meat of animals from the two genetic groups (Table 3). However, on days 7 and 14 of ageing, thawing losses were lower ($p < 0.05$) for Nellore steers. Nellore steers were older and had greater fat thickness, while there were no changes in Angus *vs.* Nellore bulls. The lower water loss by thawing in the meat from Nellore steers was due to the protection of the fat (higher fat thickness), which avoids water loss (Rotta et al., 2009).

Table 3. Water activity (thawing and cooking), texture (Warner Bratzler Shear Force – WBSF, kg) and lipid oxidation (mg malonaldehyde kg^{-1} of meat raw) of meat aged for 1, 4, 7 and 14 days from Nellore steers and Angus *vs.* Nellore bulls.

Days	Genetic groups		SEM	p < Value
	Nel.	Ang. *vs.* Nel.		
		Thawing loss, %		
1	7.84^{B}	6.73	0.48	0.260
4	8.12^{B}	7.48	0.27	0.259
7	5.01^{A}	7.41	0.42	0.002
14	5.77^{A}	8.57	0.45	0.001
SEM	0.28	0.30		
p < Value	0.001	0.155		
		Cooking loss, %		
1	24.09	29.01	1.29	0.054
4	27.40	25.71	0.69	0.232
7	24.21	27.82	0.69	0.006
14	23.21	29.80	1.09	0.001
SEM	0.64	0.61		
p < Value	0.096	0.079		
		WBSF, kg		
1	6.21^{A}	4.94^{A}	0.37	0.091
4	5.30^{A}	4.10^{B}	0.27	0.021
7	4.98^{A}	3.67^{BC}	0.27	0.013
14	4.26^{B}	3.30^{C}	0.26	0.073
SEM	0.27	0.13		
p < Value	0.001	0.001		
		TBARS, MDA		
1	0.1345^{A}	0.1733^{A}	0.01	0.239
4	0.1454^{A}	0.1614^{A}	0.01	0.439
7	0.5558^{B}	0.6789^{C}	0.02	0.007
14	0.5633^{B}	0.5444^{B}	0.01	0.610
SEM	0.03	0.03		
p < Value	0.001	0.601		

A, B: different superscript letters represent significant differences within column, ageing time ($p \leq 0.05$). *Standard error of mean.

Aging period did not influence cooking losses; however, on days 7 and 14 of ageing, thawing losses were lower ($p < 0.05$) for Nellore steers, which could also be attributed to the higher fat thickness. Water activity by thawing and cooking ranged from 5 to 8.6 and 23.2 to 29.8%, respectively. In general, those water losses for cattle finished in feedlots and slaughtered between an age of 18 and 36 months ranged from 5 to 10 and from 20 to 30%, respectively (Eiras et al., 2014; Eiras et al., 2016; Françozo et al., 2013; Rivaroli et al., 2016). Thus, the water activity by thawing and cooking observed in this study can be considered as normal.

Warner Bratzler Shear Force

Aging reduced the Warner-Bratzler shear force (WBSF) of the meat from both genetic groups (Table 3). However, the meat of bulls Angus *vs.* Nellore was more tender ($p < 0.05$) on days 4 and 7 of ageing compared to the meat of Nellore steers (Table 3). A WBSF value for cooked meat above 6 kg cm^{-1} has been suggested as the threshold that separates tender and tough meat (O'Connor, Tatum, Wulf, Green, & Smith, 1997; Shackelford, Wheeler, & Koohmaraie, 1997). Thus, at the first day, the meat of Nellore steers could be considered tough (WBSF = 6.2 kg cm^{-1}), while the meat of the Angus *vs.* Nellore bulls was tender (WBSF = 4.9 kg cm^{-1}). In fact, softer meat in animals of the European breeds is due to greater proteolysis, resulting from the higher activity of calpain present in the musculature of cattle of European origin (Boles & Swan, 2002).

Lipid oxidation (TBARS)

Genetic group had no effect ($p > 0.05$) on lipid oxidation (TBARS values) of meat (Table 3). However, ageing time increased ($p < 0.001$) lipid oxidation in the two genetic groups. The TBARS values ranged from 0.134 to 0.563 for Nellore steers and from 0.1733 to 0.5444 mg of MDA kg^{-1} of meat for Angus *vs.* Nellore bulls from day 1 to day 14, respectively. In general, lipid oxidation increases with ageing time (Prado et al., 2015). In any case, the MDA levels after 14 days of aging were below (0.55 of MDA kg^{-1} of meat) the threshold for acceptability in beef (Campo, et al., 2006). In this study, the evolution of lipid oxidation was low because the meats were packed in vacuum, which protects the meat from lipid oxidation (Rivaroli et al., 2016).

Chemical composition

Moisture, ashes, protein, lipids and collagen in the LM muscle were not altered ($p < 0.05$) by the genetic group, feeding system and slaughter weight (Table 4), with mean percentages of 72.4; 1.2 and 22.3%, respectively. These values are close to the values observed by Rivaroli et al. (2016). However, total lipids were higher (4.2%) than normally observed in meat from bulls finished in similar systems (Prado et al., 2016; Rivaroli et al., 2016; Valero et al., 2014). The high total lipid percentages may be due to the slaughter age of Nellore steers and the crossbreeding between Angus *vs.* Nellore bulls, since European animals have a higher percentage of fat in the carcass (Guerrero et al., 2016; Prado, Oliveira et al., 2009; Prado, Prado et al., 2009).

Genetic group had no effect on meat collagen content (Table 4). The total collagen content observed in the meat was low (1.5 mg 100 g^{-1} g^{-1} protein) in comparison with other studies, where

total collagen ranged between 2.0 and 5.3 mg 100 g^{-1} wet tissue (Christensen et al., 2011). In the current study, the bulls were young and, in general, young cattle present low collagen contents (Lepetit, 2008; Rivaroli et al., 2016). Also, according to Aberle, Reeves, Judge, Hunsley and Perry (1981), animals fed diets in intensive systems that provide rapid growth can have increased rates of protein turnover, including collagen, resulting in more tender meat since new collagen has a higher solubility (Burson & Hunt, 1986).

Table 4. Meat chemical composition of meat aged from Nellore steers and Angus *vs.* Nellore bulls.

Parameters	Genetic groups		SEM*	P < Value
	Nel.	Ang. *vs.* Nel.		
Moisture, %	72.47	72.41	0.12	0.807
Ash, %	1.19	1.17	0.01	0.461
Protein, %	22.06	22.66	0.09	0.432
Total lipids, %	4.25	4.15	0.14	0.744
Collagen, mg g of protein	1.52	1.53	0.02	0.989

*Standard error of mean.

Fatty acid composition

Genetic group significantly altered the percentage of the main fatty acids of the LM (Table 5). The percentages of pentadecilic ($p < 0.001$), margaric ($p < 0.002$), stearic ($p < 0.013$), ecosanoic ($p < 0.0021$), pentadecanoic ($p < 0.0147$), 15-tetracosenoic, α-linoleic ($p < 0.012$), eicosenoic ($p < 0.021$), eicosatrienoic ($p < 0.047$), eicosapentaenoic ($p < 0.016$) and decosahexaenoic ($p < 0.011$) acids were higher in the LD of the Nellore steers. On the other hand, the concentrations of tetracosanoic ($p < 0.043$), trans-octadecenoic ($p < 0.009$), oleic ($p < 0.032$), octadecenoic ($p < 0.001$), hexadecadienoic ($p < 0.001$) and linoleic ($p < 0.092$) acids were higher in the LM of the crossbred bulls Angus *vs.* Nellore. Still, for some fatty acids with a lower concentration in the LM, except for palmitic fatty acid (26.7%), genetic group had no effect (Table 5).

The concentration of palmitic acid with a lower hypercholesterolemic effect was 26.7% and is close to the values observed in previous studies for cattle finished in feedlots (Reddy et al., 2015; Rivaroli et al., 2016; Rotta et al., 2009).

The fatty acid myristic acid is considered atherogenic and therefore less desirable in meat. In this study, a low percentage of myristic acid (3%) was observed, which is considered normal for beef (Jiménez-Colmenero, Carballo, & Cofrades, 2001).

Within the class of saturated fatty acids, palmitic acid had the highest percentage (Eiras et al., 2016; Rivaroli et al., 2016; Valero et al., 2014). In this study, the values of palmitic acid were higher (20.0%) in the meat of Nellore steers than in Angus *vs.* Nellore bulls (16.6%), but this fatty acid is considered to have no effect on human health since it is transformed into oleic acid fatty (18:1n-9) in the body, therefore not influencing blood cholesterol levels (Hocquette et al., 2005). The lower proportion of stearic acid found in the meat of grain-fed animals can be explained by the decrease in ruminal biohydrogenation (Aharoni, Orlov, & Brosh, 2004). Similarly, others (Brown, Melton, Riemann, & Backus, 1979) have shown greater concentrations of stearic acid in pasture-fed *vs.* concentrate-fed cattle.

Table 5. Meat fatty acid composition of meat aged from Nellore steers and Angus *vs.* Nellore bulls.

Fatty acids		Genetic groups		SEM*	P < Value
		Nel..	Ang. *vs.* Nel.		
Saturated					
14:0	Myristic	2.95	3.36	0.12	0.105
15:0	Pentadecilic	0.49	0.31	0.03	0.001
16:0	Palmitic	26.8	26.7	0.39	0.935
17:0	Margaric	0.97	0.86	0.02	0.002
18:0	Stearic	20.0	16.6	0.76	0.013
20:0	Eicosanoic	0.76	0.58	0.07	0.238
24:0	Tetracosanoic	0.04	0.07	0.01	0.043
Monounsaturated					
14:1n-9	Tetradecenoic	1.00	0.95	0.02	0.933
15:1	Pentadecanoic	0.92	0.64	0.09	0.015
16:1n-7	Palmitoleic	2.83	2.96	0.09	0.535
17:1n-9	Heptadecenoic	1.18	0.99	0.07	0.186
18:1n-9t	Trans-octadecenoic	1.81	2.65	0.17	0.009
18:1n-9c	Oleic	33.5	36.2	0.65	0.032
18:1n-7	Octadecenoic	0.38	1.10	0.12	0.001
20:1n-9	9 – eicosenoic	0.25	0.26	0.05	0.972
24:1n-9	15-Tetracosenoic	0.45	0.16	0.06	0.009
Polyunsaturated					
16:2n-6	Hexadecadienoic	0.50	0.64	0.02	0.001
18:2n-6	Linoleic	3.23	3.96	0.21	0.092
18:3n-6	Linolenic	0.11	0.08	0.01	0.463
18:3n-3	□ – Linoleic	0.54	0.27	0.10	0.025
20:2n-6	11, 14 – Eicosenoic	0.14	0.03	0.02	0.021
20:3n-3	Eicosatrienoic	0.17	0.11	0.01	0.047
20:4n-6 (AA)	Arachdonic	0.59	0.51	0.05	0.509
20:5n-3 (EPA)	Eicosapentaenoic	0.29	0.06	0.05	0.016
22:6n-3 (DHA)	Docosahexaenoic	0.07	0.02	0.01	0.028
Saturated	SFA	52.0	48.4	0.86	0.030
Unsaturated	UFA	48.0	51.60	0.92	0.030
Monounsaturated	MUFA	42.4	45.9	0.77	0.012
Polyunsaturated	PUFA	5.64	5.68	0.22	0.925
n-6		4.57	5.22	0.24	0.210
n-3		1.07	0.46	0.13	0.009
n-6:n-3		4.27	11.35	1.26	0.004
PUFA:MUFA		0.12	0.12	0.01	0.351

*Standard error of mean.

Oleic fatty acid percentage was higher in the meat of crossbred Angus *vs.* Nellore bulls than in that of Nellore steers. This result was expected, since the Angus *vs.* Nellore bulls were fed in feedlots with a high grain diet. Such feeding systems generally result in meat with higher percentage of oleic fatty acids due to the high content of this fatty acid in grains (Realini, Duckett, Brito, Dalla Rizza, & Mattos, 2004; Rotta et al., 2009).

Intramuscular fat from pasture-fed Nellore steers had greater concentrations of total CLA and

CLA isomer cis-9, trans-11 than the fat of feedlot-fed Angus *vs.* Nellore bulls. Previous research has shown that including pasture in the diet of dairy and beef cattle increased CLA concentrations in milk and in beef intramuscular fat, respectively (French et al., 2000; Yang, Lanari, Brewster, & Tume, 2002).

The fatty acids considered most important to human health, namely linolenic, α-linolenic, eicosenoic, EPA and DHA, were higher in the meat of Nellore steers than in that of Angus *vs.* Nellore bulls. Nellore steers were fattened in pasture systems, while Angus *vs.* Nellore bulls were fattened in feedlot systems. In general, these major fatty acids are higher in grazing cattle (French et al., 2000; Realini et al., 2004; Yang et al., 2002).

The meat of Nellore steers contained a higher ($p < 0.05$) percentage of saturated fatty acids (SFA), a lower percentage of unsaturated (UFA, $P < 0.05$) and monounsaturated fatty acids (MUFA, $p < 0.05$) and a similar ($p > 0.05$) percentage of polyunsaturated fatty acids (PUFA) compared to that from Angus *vs.* Nellore bulls (Table 5).

The highest percentage of SFA and the lowest percentage of UFA and MUFA in the meat of Nellore steers is due to the breed and slaughter age of the animals. Older cattle have a higher percentage of SFA in their meat and, consequently, a lower percentage of UFA (Reddy et al., 2015; Rotta et al., 2009).

Current recommendations are that the PUFA: SFA ratio should be around 0.45 (Her Majesty's Stationary Office [HMSO], 1994). However, in this study, the ratio was lower than the recommended ratio, with a value of 0.12 for both genetic groups. Similar PUFA: SFA ratios for cattle have been reported for typical retail beef in Brazil - 0.13, (Valero et al., 2014); 0.12 (Rivaroli et al., 2016).

The intramuscular fat of Nellore steers-fed cattle had a more favourable n-6:n-3 fatty acid ratio than that of Angus *vs.* Nellore bulls (4.37 vs. 11.45, respectively). An increase in the consumption of n-3 fatty acids is recommended (HMSO, 1994) to overcome the imbalance in the ratio of n-6:n-3 PUFA in most current diets (4-10:1) compared with the primitive man (1:1) (Eaton, Eaton III, Konner, & Shostak, 1996). Mitchell, Reed and Rogers (1991) reported that adipose tissues from pasture-based diets had higher concentrations of n-3 PUFA in body tissues, while concentrate-based diets had higher concentrations of n-6 PUFA. These differences are a consequence of the fatty acid composition of the diet, with α-linolenic acid (C18:3, the n-3 series precursor) being the major fatty acid in grass lipids and linoleic acid (C18:2, the n-6 series precursor) being a major component in grains (Manner, Maxwell, & Williams, 1984). Similarly, previous research has found a lower n-6:n-3 PUFA ratio in pasture-fed cattle than in concentrate-fed cattle. Rule, Broughton, Shellito and Maiorano (2002) reported n-6:n-3 ratios of 1.95 and 6.38 for pasture-fed cows and feedlot steers, respectively, while French et al. (2000) reported ratios of 2.33 and 4.15 for grass-fed and concentrate-fed steers.

Consumer acceptability

Tenderness, flavour and overall acceptability were higher ($p < 0.001$) for meats of Nellore steers, regardless of ageing time (1, 4, 7 or 14 days) (Table 6). Thus, for a small population in southern Brazil, the meat of 36-month-old Nellore steers is more highly appreciated than meat of 24-month-old Angus *vs.* Nellore bulls finished in feedlots.

Likewise, ageing time was a significant factor ($p > 0.001$) for tenderness, flavour and overall acceptability of meat (Table 6). Meat aged for 14 days was higher valued by the consumers (score above 7.7) while meats aged for 4 and 7 days were intermediate (scores close 7.2); meats not aged were the least valued (score close 6.6). Ageing time influences the development of flavour precursors. Usually, ageing improves meat acceptability before the meat reaches long ageing, which could develop off-flavours (Monsón, Sañudo, & Sierra, 2005).

A clustering analysis was performed to identify different market niches within the population studied (Table 7).

Table 6. Consumer acceptability of meat aged for 1, 4, 7 and 14 days from Nellore steers and Angus *vs.* Nellore bulls.

	Genetic groups								
s	Nel.	Ang *vs.* Nel.	p < Value	Nel.	Ang. *vs.* Nel.	p < Value	Nel.	Ang. *vs.* Nel.	p < Value
	Attributes								
	Tenderness			Flavor			Overall acceptability		
1	6.77^{C}	6.09^{C}	0.011	6.92^{C}	6.48^{C}	0.001	6.92^{C}	6.22^{C}	0.001
4	7.48^{B}	6.68^{B}	0.003	7.21^{B}	6.71^{B}	0.001	7.56^{B}	6.69^{B}	0.002
7	7.83^{A}	6.79^{B}	0.002	7.49^{AB}	6.93^{B}	0.002	7.50^{B}	7.18^{B}	0.002
14	8.12^{AB}	7.66^{A}	0.001	7.76^{A}	7.50^{A}	0.003	7.87^{A}	7.42^{A}	0.001
SEM*	0.05	0.06		0.05	0.04		0.08	0.07	
p < Value	0.001	0.001		0.001	0.001		0.001	0.001	

A, B: different superscript letters represent significant differences within column, ageing time ($p \leq 0.05$). *Standard error of mean.

Table 7. Clusters of meat aged for 1, 4, 7 and 14 days from Nellore and Angus *vs.* Nellore bulls.

Attributes												
Days	Cluster 1			Cluster 2			Cluster 3			Cluster 4		
	Nel.	Ang *vs.* Nel.	p < Value	Nel.	Ang. *vs.* Nel.	p < Value	Nel.	Ang. *vs.* Nel.	p < Value	Nel.	Ang *vs.* Nel	p < Value
1	5.29C	4.88C	0.05	6.35C	5.97C	0.06	6.89B	2.00C	0.03	7.98AB	7.81B	0.04
4	7.59AB	3.65D	0.05	6.52ABC	6.26BC	0.07	7.22AB	7.22B	0.03	8.37A	8.09AB	0.05
7	6.59B	6.59B	0.04	6.65ABC	6.06C	0.05	8.22A	7.89A	0.04	8.44A	8.07AB	0.06
14	8.18A	5.18C	0.05	6.94AB	7.26A	0.04	8.11A	8.00A	0.05	8.37A	8.30A	0.06
SEM*	0.06	0.04		0.04	0.06		0.04	0.05		0.05	0.06	
p < Value	0.001	0.001		0.001	0.001		0.001	0.001		0.001	0.001	

A, B: different superscript letters represent significant differences within column, ageing time. *Standard error of mean.

Four different consumer groups were found in relation to the global acceptance of meat. Cluster 1 covered 17% of the consumers, who preferred meat from Nellore steers. For ageing, the most highly accepted meat was aged for 7 and 14 days, for both genetics groups. This cluster included a similar percentage of men (54%) and women (46%); 59% of whom were between 18 and 34 years old.

The consumers grouped in cluster 2 consisted of 31% of the evaluated population; these consumers did not perceive differences between the genetic groups, but only between ageing time, and preferred longer ageing, mainly meat aged 14 days of Angus *vs.* Nellore bulls. This cluster included a similar percentage of men (51.2%) and women (48.8%); 80.6% were between 18 and 44 years old.

Cluster 3 was comprised of 9% of the consumers who valued the Zebu meat more highly. Meat of the Angus *vs.* Nellore bulls was little accepted (2 points), and the preference was rising for all treatments with increasing ageing time. This cluster included a similar percentage of men (50.0%) and women (55.5%); 80.6% were between 35 and 54 years of age.

Cluster 4 grouped the largest number of consumers (43%) who highly values the two meat types, giving scores above 8 points, but meat from Zebu cattle was still preferred one ($p < 0.05$). In terms of aging, the meat at day 1 obtained the lowest score in both genetic groups. For the Nellore steers, consumers did not differentiate between 4, 7 and 14 d of aging in terms of general acceptability of the meat. On the other hand, the acceptability of meat from Angus *vs.* Nellore bulls increased with a longer ageing period. This cluster included a similar percentage of men (49.1%) and women (50.9%), with a heterogeneous age range between 18 and over 65 years.

Figure 1 shows the results of the analysis of principal components. Only one main component axis (PC) explained 97.5% of the total variation. The attributes aroma, flavour, softness and general acceptance are on the right side of F1, located near the graph for treatments with longer aging periods. Angus *vs.* Nellore meats aged for 1 day and for up to 7 days and Nellore meats aged for 1 day are placed on the left side of F1, inversely related to acceptability attributes.

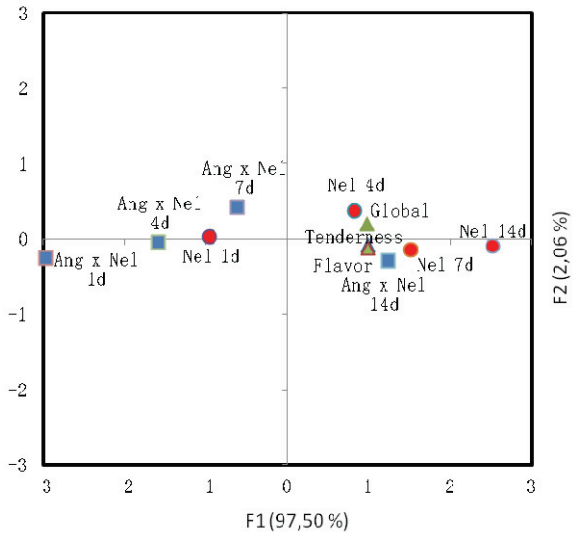

Figure 1. Principal component analysis of the scores for tenderness, flavor and overall acceptability of meat aged for 1, 4, 7 and 14 days from Nellore steers and Angus *vs.* Nellore bulls.

Conclusion

Nellore cattle are slaughtered at a higher age (36 months) than crossbred Zebu x European bulls (20 months). Therefore, slaughter weight and carcass weight as well as carcass characteristics highly correlated with slaughter weight are expected to be higher for Nellore animals. On the other hand, the breed of the animal had little influence on meat water, colour and lipid oxidation, but the meat of Nellore bulls obtained a higher instrumental value (i.e. WBSF value) for tenderness. Also, the composition of the main fatty acids (essential) was superior in the meat of Nellore steers. Likewise, in the sensorial evaluation by consumers of southern Brazil, the meat of Nellore bulls and that aged for 14 days received the highest scores.

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