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Physicochemical properties of meat from *Bos taurus* and *Bos indicus*[1]

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ABSTRACT - The objective of this study was to characterize meat quality in *Bos taurus* and *Bos indicus* and to determine the influence of finishing system and genetic group on the physicochemical properties of the *longissimus thoracis* at 24 hours and 10 days *post mortem* (1ºC). The sample included 160 bulls of the *B. taurus* (n=75) and *B. indicus* (n=85) groups, finished either on pasture (n=46) or with grain supplementation (n=114), slaughtered at a carcass weight of 270 to 300 kg. Pasture-finished animals had higher pH, lower red content and a fat content 2.5 times lower than those finished with supplementation. Meat from supplement-finished animals had lower shear force in comparison to that from animals finished on pasture, with means of 7.7 and 8.5 kg at 24 hours, and of 5.5 and 5.9 kg at 10 days, respectively. Samples of *B. taurus* and *B. indicus* were similar in moisture and protein, but *B. taurus* presented higher means for ash and lower means for fat. Aged samples of *B. indicus* finished on pasture showed lower values for lightness and yellowness. Overall, lightness and yellow content increased and red content decreased with 10-day ageing. Means for shear force were lower in *B. taurus* than in *B. indicus*, with differences of 1.4 kg in fresh meat and 0.6 kg in aged samples. The reduction in shear force with ageing was more pronounced in samples with higher initial shear force, in spite of the positive relationship between shear force before and after ageing.

Key Words: beef, finishing system, genetic group, meat quality

Propriedades físico-químicas de carnes de *Bos taurus* e *Bos indicus*

RESUMO - Este estudo foi conduzido com os objetivos de caracterizar a qualidade de carnes de *Bos taurus* e *Bos indicus* e determinar a influência do sistema de terminação e dos grupos genéticos nas propriedades físico-químicas do músculo *longissimus thoracis* às 24 horas e aos 10 dias *post mortem* (1ºC). Na amostragem foram usados 160 bovinos *B. taurus* (n=75) e *B. indicus* (n=85) terminados a pasto (n=46) ou com suplementação de grãos (n=114), abatidos com peso de carcaça entre 270 a 300 kg. O teor de gordura foi 2,5 vezes mais baixo em animais terminados a pasto. A carne dos animais terminados com suplementação apresentou pH mais baixo, com maior teor de vermelho, e força de cisalhamento mais baixa em comparação à dos animais terminados a pasto, com médias de 7,7 e 8,5 kg (24 horas) e 5,5 e 5,9 kg (10 dias), respectivamente. Amostras de *B. taurus* e *B. indicus* foram similares em umidade e proteína, porém as de *B. taurus* mostraram média mais alta de cinzas e mais baixas de gordura. Amostras maturadas de *B. indicus* terminados a pasto mostraram valores mais baixos de luminosidade e índice de amarelo. Em geral, a luminosidade e o teor de amarelo aumentaram e o teor de vermelho diminuiu com a maturação de dez dias. As médias de força de cisalhamento foram mais baixas em *B. taurus* que em *B. indicus*, com diferenças de 1,4 kg na carne fresca e 0,6 kg em amostras maturadas. A redução na força de cisalhamento com a maturação é mais pronunciada em amostras com alta força de cisalhamento inicial, apesar da relação positiva com a força de cisalhamento antes e após a maturação.

Palavras-chave: bovinos, grupo genético, qualidade de carne, sistema de terminação

Introduction

With nearly 170 million cattle, Brazil is the second largest beef producing country in the world and has been the leading exporter of beef over the last few years (USDA, 2007). Beef production systems in Brazil are extremely diversified. In northern Brazil the climate is predominantly tropical and subtropical and *B. indicus* breeds are used extensively there whereas in the south, the climate is cooler, and cattle production is based on *B. taurus* breeds. Overall, it is estimated that nearly 83% of beef production in Brazil is from Zebu breeds and their crosses (Mariante et al., 2003). Finishing of commercial beef cattle usually takes place in pasture, but feedlot

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finishing is also adopted for a period of about 3 months (Lopes & Magalhães, 2005).

The diversity of production conditions and genetic background in Brazilian commercial beef cattle is expected to result in considerable variability in beef quality, as it is known that both finishing system and genotype will influence meat quality. Several studies have shown that, when compared with *B. taurus* breeds, meat from *B. indicus* has reduced tenderness (Wheeler et al., 2001), presumably due to increased *post mortem* activity of calpastatin (Shackelford et al., 1991; O'Connor et al., 1997), but studies on the effects of zebu inheritance on meat color have shown inconsistent results (Silveira et al., 2006). When compared with pasture-based systems, supplement-finishing results in meat with higher fat content (French et al., 2001) and lighter color (Bruce et al., 2004), but the influence on meat tenderness is not clear (Realini et al., 2004).

The objectives of this work were to characterize meat quality in commercial beef cattle in Brazil by analyzing the physicochemical characteristics of the *longissimus thoracis* in a sample of animals processed by the packing industry, and to assess the influences of finishing system and genetic group on beef quality attributes.

Material and Methods

In this work, M. *longissimus thoracis* (LT) samples were collected from 160 commercial bulls, at 26 to 40 months of age (corresponding to the typical age range for commercial beef cattle in Brazil), with carcass weight ranging from 270 to 300 kg, slaughtered in a processing plant certified for beef exporting.

Sampling was carried out in an attempt to represent the range of genotypes and production conditions typically observed in Brazil, and included animals of the genetic groups *B. taurus* (n=75) and *B. indicus* (n=85), which were classified as having been finished either on pasture (FP) or with grain supplementation (FG). In FP (n=46, of which 20 were *B. taurus* and 26 were *B. indicus*), animals were raised on grass (*Brachiaria brizantha* cv. Marandu, *Brachiaria decumbens, Brachiaria humidicula* and *Panicum maximum* Jacq.) in the Brazilian state of Minas Gerais, whereas in FG (n=114, of which 55 were *B. taurus* and 59 *B. indicus*) a finishing period of about 90 days was adopted, when animals were supplemented with about 50% roughage (chopped sugar cane) and 50% concentrate (consisting of 40.5% corn, 6% soybean meal, 1.5% urea and 2% minerals and vitamins).

Animals were slaughtered humanely after 14 hours of fasting, according to official procedures, with electrical stimulation of the carcass. Carcasses were chilled at 0ºC, and cold-boned at 24 hours *post mortem*. At this time, a sample of the LT with approximately 500 g was collected between the 5th and the 7th rib of the carcass left side, individually vacuum-packaged, frozen at -30ºC to -35ºC, and stored at -20ºC until further analyses.

Meat pH at 24 hours was measured by making a scalpel incision in the LT between the 12th and 13th rib, and inserting a glass electrode attached to a portable pH meter M 1120× (Mettler-Toledo International Inc., Columbus, EUA), approximately 2.5 cm into the muscle. From each point, three pH measurements were taken, and the mean of these measurements was used for statistical analyses.

After approximately 30 days of frozen storage, samples were thawed at 4ºC for 24 h, trimmed of subcutaneous fat and connective tissue in the surface and separated into two different portions, which were either immediately analyzed or submitted to ageing for 10 days at 1ºC. From both fresh and aged samples, three slices with a thickness of 15 mm were obtained by sectioning the LT perpendicular to the muscle fibers. After 30 minutes of blooming at 4ºC, a colorimeter Cr-400 (Minolta Camera Co., Ltd., Osaka, Japan) and the D65 illuminant were used to measure lightness (L*), redness (a*) and yellowness (b*) of the surface of the LT slice, according to the CIE color scores. From each steak, three color measurements were obtained, and the mean of the nine measurements per animal was used for further analyses. The L*, a* and b* color coordinates were obtained in both fresh (24 hours *post mortem*) and aged (10 days *post mortem*) meat samples.

Cooking loss was estimated in fresh (24 hours *post mortem*) and aged (10 days *post mortem*) meat, according to the procedures recommended by AMSA (1978). Briefly, steaks were weighed and then grilled in aluminum foil at 150ºC, until reaching an internal temperature of 65ºC. After cooling, steaks were weighed again, and the difference in weight before and after broiling, expressed as a percentage of initial weight, was considered to correspond to cooking loss. The three measurements obtained per carcass-ageing time combination were averaged for further analyses.

Meat tenderness was evaluated by using peak Warner-Bratzler shear force, in both fresh (24 hours *post mortem*) and aged (10 days *post mortem*) meat. From each cooked steak, three cores (1× 1 cm) were cut parallel to the direction of the muscle fibers, and sheared by using a texturometer TA-XT2 (Stable Micro System, Surrey, England), equipped with a Warner-Bratzler shearing device, with a layer of 1.016 mm (pre-test speed 1.00 mm/s, post-test speed 5.00 mm/s, distance 25.00 mm). Results were expressed

in kg, and the mean of nine measurements (three slices with three replicates per slice) per carcass-ageing time combination was used for statistical analyses.

Samples of fresh and aged meat were minced in a commercial mixer-blender until a homogeneous mass was obtained, and chemical analyses were carried out in duplicate. Crude protein was estimated by the method of Kjeldahl and fat by Soxhlet (AOAC, 1995). Moisture was determined in an oven at 105ºC until a constant weight was reached, and ash concentration was determined on the residue of samples after drying for 12 h at 550ºC. For cholesterol determination, fat was extracted from LT samples as described by Folch et al. (1957), and cholesterol was quantified by colorimetry, with a modification of the method of Bohac et al. (1988), as described by Bragagnolo & Rodriguez-Amaya (2001). All chemical components were expressed as percentages of the meat sample, except for cholesterol, which was expressed in mg/100 g of meat.

Before carrying out statistical analyses, changes in meat quality with ageing for 10 days were computed per animal, by calculating the differences between samples before and after ageing, for the L*, a* and b* color coordinates (L_d, a_d and b_d, respectively), for cooking loss (CL_d) and for shear force (SF_d).

The data were considered to have originated from a factorial design with two genetic groups and two finishing systems, and the GLM procedure of SAS (SAS Institute, 2004) was used in analyses of variance to study the effects of finishing system, genetic group and their interaction, on the response variables evaluated, i.e., color coordinates, cooking loss and shear force, all measured in fresh and aged meat, as well as changes in these variables with ageing. The same linear model was used in the analysis of pH, crude protein, fat, moisture, ash and cholesterol. If the interaction was not significant (P>0.05), it was dropped from the model, and the data re-analyzed with a model including only the main effects of genetic group and finishing system. Correlations among variables were estimated with the CORR procedure of SAS (SAS, 2004), both for the full data set and within finishing system, to assess the relationship among the variables studied. Differences among correlation coefficients estimated by finishing system were tested by using Fisher Z-transformation (Snedecor & Cochran, 1989).

Table 1 - Descriptive statistics, statistical significance of factors considered in the analyses of variance of physicochemical characteristics of muscle *longissimus thoracis* in beef cattle

Variable	Mean ± standard deviation	Significance			
		System	Group	System*Genetic group	R^2
Moisture (%)	72.63 ± 2.06	**	ns	ns	0.14
Crude protein (%)	19.08 ± 1.70	**	ns	ns	0.73
Ash (%)	0.90 ± 0.18	**	**	ns	0.15
Fat (%)	6.39 ± 3.13	**	ns	ns	0.46
Cholesterol (mg/100 g)	49.27 ± 16.00	**	**	**	0.65
pH	5.85 ± 0.18	**	ns	ns	0.07
Lightness (L*)					
24 hours *post mortem*	32.76 ± 2.43	ns	ns	**	0.07
10 days *post mortem*	33.61 ± 2.66	**	*	**	0.22
Fresh meat – aged meat (L_d)	–0.86 ± 2.62	**	**	*	0.14
Redness (a*)					
24 hours *post mortem*	19.99 ± 1.56	**	ns	ns	0.09
10 days *post mortem*	16.51 ± 2.08	ns	ns	ns	0.03
Fresh meat – aged meat (a_d)	3.49 ± 2.39	ns	ns	ns	0.02
Yellowness (b*)					
24 hours *post mortem*	4.23 ± 1.16	0.12	0.09	**	0.05
10 days *post mortem*	4.87 ± 1.39	0.50	**	**	0.15
Fresh meat – aged meat (b_d)	–0.65 ± 1.45	0.06	**	ns	0.09
Cooking loss (%)					
24 hours post mortem	29.06 ± 4.66	ns	ns	ns	0.01
10 days *post mortem*	30.19 ± 5.16	ns	ns	ns	0.03
Fresh meat – aged meat (CL_d)	–1.14 ± 6.85	ns	ns	ns	0.04
Shear force (kg)					
24 hours *post mortem*	7.98 ± 1.69	**	**	ns	0.22
10 days *post mortem*	5.64 ± 1.52	ns	**	ns	0.06
Fresh meat – aged meat (SF_d)	2.34 ± 1.74	ns	*	ns	0.06

** Significant at the 1% level (P<0.01), *Significant at the 5% level (P<0.05); ns = non-significant (P>0.05).

Results and Discussion

With the exception of crude protein, fat, cholesterol, 10- day L* and 24-hour shear force, the factors considered in the statistical model explained only less than 20% of the variability observed (Table 1), as it would be expected in a study conducted with commercial beef cattle, given the high variability among individuals. Nevertheless, for crude protein, fat and cholesterol, the coefficient of determination ranged between 46 and 73%.

The interaction between genetic group and finishing system was significant (P<0.05) for cholesterol, 24 hour-L*, 10 day-L*, L_d, 24 hour-b* and 10-day b* , but not for the other variables. The finishing system affected significantly (P<0.05) moisture, crude protein, fat, ash, cholesterol, pH, 10-day L*, L_d, 24 -hour a*, and 24-hour shear force , whereas the genetic group had a significant influence (P<0.05) on ash, cholesterol, 10-dayL* , L_d, 10-day b* , b_d, 24- hour shear force , and 10-day shear force.

Depending on the significance of the interaction, the least squares means for the different variables are presented for combinations of finishing system with genetic group, or individually by finishing system and by genetic group (Table 2).

When compared with FG (Table 2), samples from FP animals had higher moisture, crude protein and ash which were higher by 1.60%, 3.20% and 0.10%, respectively (P<0.01), but crude fat was 4.70% lower (P<0.01). Finishing system affected significantly the pH of meat (P<0.01), with an average pH which was 0.10 units lower in FG animals.

Redness of fresh meat from FP animals was lower by 1.00 units when compared with FG (P<0.05), whereas in aged meat redness was similar (P>0.05) for the two finishing systems (Table 2). Redness dropped significantly (P<0.01)

Table 2 - Physicochemical characteristics of M. *longissimus thoracis* of beef cattle, by finishing system, genetic group and for combinations of finishing system and genetic group

	Finishing system		Genetic group		Finishing system * genetic group			
					Pasture		Grain	
Variable[2]	Pasture	Grain	Taurus	Indicus	Taurus	Indicus	Taurus	Indicus
Moisture (%)	73.8 ± 0.28a	72.2 ± 0.18b	73.3 ± 0.24	72.7 ± 0.22	-	-	-	-
Crude protein (%)	21.4 ± 0.13a	18.2 ± 0.08b	19.7 ± 0.11	19.8 ± 0.10	-	-	-	-
Ash (%)	0.97 ± 0.03a	0.87 ± 0.02b	0.97 ± 0.02a	0.87 ± 0.02b	-	-	-	-
Fat (%)	3.0 ± 0.34a	7.7 ± 0.22b	5.0 ± 0.28a	5.7 ± 0.26b	-	-	-	-
Cholesterol (mg/100 g)	-	-	-	-	45.5 ± 2.15a	36.9 ± 1.88b	38.8 ± 1.30b	65.8 ± 1.25c
pH	5.92 ± 0.03a	5.82 ± 0.02b	5.86 ± 0.02	5.87 ± 0.02	-	-	-	-
Lightness (L*)								
24 hours *post mortem*	-	-	-	-	33.0 ± 0.53ab	32.3 ± 0.47a	32.1 ± 0.32a	33.5 ± 0.31b
10 days *post mortem*	-	-	-	-	33.9 ± 0.53ab	30.9 ± 0.46c	33.7 ± 0.32a	34.7 ± 0.31b
Fresh meat – aged meat (L_d)	-	-	-	-	–0.9 ± 0.55a	1.3 ± 0.48b	–1.6 ± 0.33a	–1.15 ± 0.32a
Significance of L_d	-	-	-	-	ns	**	**	**
Redness (a*)								
24 hours *post mortem*	19.3 ± 0.22a	20.3 ± 0.14b	19.8 ± 0.18	19.8 ± 0.17	-	-	-	-
10 days *post mortem*	16.1 ± 0.31a	16.7 ± 0.19a	16.5 ± 0.25	16.3 ± 0.24	-	-	-	-
Fresh meat – aged meat (a_d)	3.2 ± 0.35a	3.6 ± 0.22a	3.4 ± 0.29	3.5 ± 0.27	-	-	-	-
Significance of a_d	**	**	**	**	-	-	-	-
Yellowness (b*)								
24 hours *post mortem*	-	-	-	-	4.9 ± 0.26a	4.0 ± 0.22b	4.1 ± 0.15b	4.2 ± 0.15b
10 days *post mortem*	-	-	-	-	5.7 ± 0.29a	3.9 ± 0.26b	5.2 ± 0.18a	4.7 ± 0.17c
Fresh meat – aged meat (b_d)	–0.33 ± 0.21a	–0.81 ± 0.13b	–0.94 ± 0.17a	–0.19 ± 0.16b	-	-	-	-
Significance of b_d	ns	**	**	ns	-	-	-	-
Cooking loss (%)								
24 hours *post mortem*	29.9 ± 0.69	28.7 ± 0.44	29.3 ± 0.57	29.3 ± 0.53	-	-	-	-
10 days *post mortem*	29.3 ± 0.76	30.5 ± 0.48	29.8 ± 0.63	30.0 ± 0.59	-	-	-	-
Fresh meat – aged meat (CL_d)	0.59 ± 1.00a	–1.82 ± 0.64b	–0.50 ± 0.83	–0.73 ± 0.77	-	-	-	-
Significance of CL_d	ns	**	ns	ns	-	-	-	-
Shear force (kg)								
24 hours *post mortem*	8.5 ± 0.22a	7.7 ± 0.14b	7.4 ± 0.18a	8.8 ± 0.17b	-	-	-	-
10 days *post mortem*	5.9 ± 0.22a	5.5 ± 0.14b	5.4 ± 0.18a	6.0 ± 0.17b	-	-	-	-
Fresh meat – aged meat (SF_d)	2.6 ± 0.25a	2.2 ± 0.16a	2.0 ± 0.21a	2.7 ± 0.19b	-	-	-	-
Significance of SF_d	**	**	**	**	-	-	-	-

** Significant at the 1% level (P<0.01), * Significant at the 5% level (P<0.05); ns = non-significant (P>0.05).
[1] For a given factor or combination of factors, means without a common letter differ (P<0.05) by Tukey test.

with ageing (a_d), by a similar amount in the two finishing systems (P>0.05). Differences among finishing systems in meat lightness and yellowness depended on the genetic group considered, both in fresh and aged meat. Yellowness increased with ageing in FG animals (P<0.01), but changes were minor in FP (P>0.05) whereas the changes in lightness (L_d) with finishing system depended on genetic group.

Cooking loss in fresh and aged meat was similar (P>0.05) for the two finishing systems (Table 2), but the ageing process resulted in a significant (P<0.01) drop (CL_d) in FG samples whereas no significant changes occurred with ageing in FP samples (P>0.05).

The shear force in fresh and aged meat was significantly (P<0.05) higher in FP samples, with a difference of 0.80 and 0.40 kg, respectively, when compared with FG samples. The ageing process resulted in a significant (P<0.01) decrease in shear force, of 2.60 kg in FP and 2.20 kg in FG, which did not differ from each other (P>0.05).

B. taurus and *B. indicus* groups did not differ (P>0.05) in meat moisture, crude protein content, pH, as well as in redness and cooking loss, both in fresh and aged meat. On the other hand, differences between *B. taurus* and *B. indicus* were found in ash, fat, b_d, 24-hour shear force, 10-day shear force and SF_d, whereas differences between genetic groups in cholesterol, 24-hour L*, 10-day L* , L_d, 24-hour b* and 10 day-b* depended on the finishing system.

The amount of ash (Table 2) was higher in *B. taurus* by 0.1% whereas the mean fat was 0.70% higher (P<0.05) in *B. indicus*. The increase in yellowness with meat ageing (b_d) was higher by 0.75 units in *B. taurus* when compared with *B. indicus* (P<0.05).

The shear force was lower (P<0.01) in *B. taurus* than in *B. indicus*, by 1.40 kg in fresh and by 0.60 kg in aged samples. Shear force declined with ageing in both genetic groups (P<0.01), but SF_d differed between them (P<0.05), with a mean SF_d of 2.00 kg in *B. taurus*, and 2.70 kg in *B. indicus*.

Meat lightness in samples of FG animals was higher in *B. indicus* by 1.40 units in fresh meat and 1.00 units in aged meat (P<0.05). However, lightness was similar in fresh meat from both genetic groups in FP animals (P>0.05) whereas in aged meat lightness was higher by 3.00 units in *B. taurus* (P<0.05). Overall, lightness increased with ageing in both genetic groups in FG (P<0.01), but in FP a decline in lightness was observed in *B. indicus* samples, and no significant changes were observed in *B. taurus* (P>0.05).

Yellowness of fresh and aged meat was higher (P<0.05) in *B. taurus* than in *B. indicus* in FP, by 0.90 and 1.80 points, respectively. In FG, 24-hour b* was similar for the two genetic groups (P>0.05), but 10-day b* was higher by 0.50 units in *B. taurus* (P<0.05).

The differences among genetic groups in cholesterol content were highly dependent on the finishing system considered, with higher cholesterol levels in *B. taurus* under pasture-finishing (about 8.60 mg, P<0.05), but much higher for *B. indicus* in the FG system (about 27 mg, P<0.05).

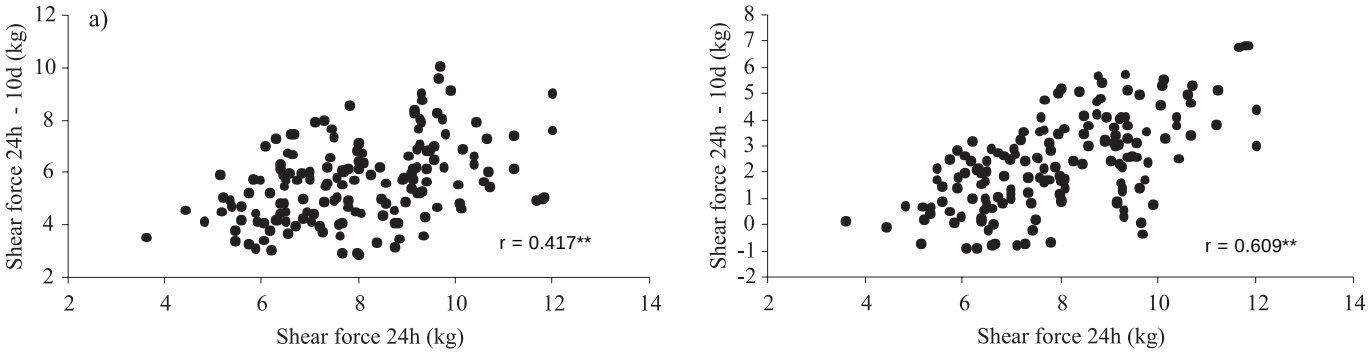
The samples of LT muscle from *B. taurus* and *B. indicus* animals, finished on pasture or with grain supplementation, showed changes in color L*, a* and b*coordinates, when subject to an ageing process of 10 days at 1ºC. In FG animals, meat became lighter with ageing (Table 2), whereas in FP, ageing resulted in darker meat in *B. indicus* but no changes (P>0.05) were observed in *B. taurus* animals. Ageing of meat also resulted in a decrease in redness (P<0.01), which was similar in both finishing systems and genetic groups (P>0.05). On the other hand, yellowness increased with ageing in *B. taurus* and FG (P<0.01) whereas changes were minor in FP and in *B. indicus* (P>0.05).

Cooking loss increased with ageing in FG animals (P<0.01), but no significant changes were observed in FP (P>0.05). When analyzed by genetic group, cooking loss did not change with ageing (P>0.05) in neither of them.

Meat tenderness improved substantially with ageing (P<0.01) by a similar amount in the two finishing systems (P>0.05). The decrease in shear force with ageing was observed in the two genetic groups (P<0.01), but it was higher in *B. indicus* when compared to *B. taurus* (P<0.05).

The relationship of 24-hour shear force with 10-day shear force and SF_d (Figure 1) indicates that meat with higher 24-hour shear force tended to also have higher 10-day shear force (r = 0.417; P<0.01), even though the improvement in meat tenderness with the ageing process was higher as shear force increased in fresh meat (r = 0.609; P<0.01). This is in line with the finding that the *B. indicus* group, which had the highest 24-hour shear force, benefited more from ageing in terms of meat tenderness, although the 10-day shear force was still higher in *B. indicus*, but with a much lower difference from *B. taurus* than what was observed for 24-hour shear force.

The correlation coefficients (Table 3) indicate that the stronger relationships were found among variables in the same category, i.e., among color coordinates, physical variables and chemical components, whereas the relationships among variables in different categories were generally not significant (P>0.05), the major exceptions being the correlation of shear force with crude protein, and with meat redness and yellowness, and of meat lightness and redness with crude protein and fat.



** Significant at the 1% level (P<0.01).

Figure 1 - Relationship between shear force in fresh meat (24 hours *post mortem*) and: a) shear force after ageing (10 days *post mortem*); b) difference in shear force in fresh and aged meat.

Table 3 - Correlations between physico-chemical characteristics of the *M. longissimus thoracis* in commercial Brazilian beef [1]

	L_{24h}	L_{10d}	L_d [2]	a_{24h}	a_{10d}	a_d [3]	b_{24h}	b_{10d}	b_d [4]	CL_{24h}	CL_{10d}	CL_d [5]	SF_{24h}	SF_{10d}	SF_d [6]	Mo	CP	As	Fat	Ch
pH	-0.01	-0.12	0.11	-0.04	*-0.18*	0.13	0.01	*-0.19*	*0.19*	-0.11	**-0.23**	0.10	0.02	0.04	-0.02	**0.26**	**0.28**	-0.03	**-0.29**	-0.07
L_{24h}		**0.47**	**0.45**	-0.15	0.03	-0.12	**0.54**	**0.25**	*0.19*	0.08	0.11	-0.03	0.08	0.13	-0.03	-0.13	-0.09	*-0.16*	0.13	**0.27**
L_{10d}			**-0.57**	0.10	-0.13	*0.18*	**0.36**	**0.56**	**-0.25**	-0.08	0.05	-0.10	0.00	-0.04	0.04	-0.15	**-0.34**	-0.11	**0.26**	**0.28**
L_d [2]				**-0.24**	*0.16*	**-0.29**	0.13	**-0.33**	**0.42**	*0.16*	0.05	0.07	0.07	*0.16*	-0.07	0.04	**0.26**	-0.03	-0.15	-0.04
a_{24h}					*0.16*	**0.51**	**0.22**	0.09	0.10	-0.11	-0.01	-0.06	0.05	0.00	0.05	*-0.19*	*-0.19*	*-0.19*	**0.25**	0.09
a_{10d}						**-0.77**	0.04	0.03	0.01	-0.11	0.10	-0.15	**-0.22**	*-0.18*	-0.05	-0.09	-0.13	-0.06	0.15	0.06
a_d [3]							0.11	0.03	0.06	0.03	-0.10	0.09	**0.22**	*0.16*	0.08	-0.05	-0.01	-0.07	0.03	0.00
b_{24h}								**0.36**	**0.45**	0.00	*0.19*	-0.14	0.04	0.05	0.00	0.00	0.05	-0.13	-0.04	0.05
b_{10d}									**-0.67**	-0.04	*0.19*	*-0.17*	**-0.25**	-0.08	*-0.17*	0.03	-0.11	0.08	0.02	-0.07
b_d [4]										0.04	-0.03	0.05	**0.27**	0.12	*0.16*	-0.02	0.15	*-0.18*	-0.04	0.11
CL_{24h}											0.03	**0.66**	*0.20*	0.14	0.07	0.02	0.09	-0.03	-0.07	-0.05
CL_{10d}												**-0.73**	-0.14	*0.20*	**-0.31**	-0.02	-0.14	-0.05	0.07	0.04
CL_d [5]													**0.24**	-0.05	**0.28**	0.02	*0.17*	0.02	-0.10	-0.06
SF_{24h}														**0.42**	**0.61**	-0.02	**0.23**	-0.04	-0.11	*0.17*
SF_{10d}															**-0.47**	0.09	0.15	-0.02	-0.15	0.07
SF_d [6]																-0.09	0.10	-0.02	0.02	0.10
Mo																	**0.37**	**0.35**	**-0.88**	**-0.37**
CP																		*0.19*	**-0.74**	**-0.24**
As																			**-0.40**	**-0.47**
Fat																				**0.40**

[1] Significant correlations are in italic (P<0.05) and in bold (P<0.01).
[2] L_d = difference in lightness (L*) between fresh (24 hours *post mortem*) and aged (10 days *post mortem*) meat.
[3] a_d = difference in redness (a*) between fresh (24 hours *post mortem*) and aged (10 days *post mortem*) meat.
[4] b_d = difference in yellowness (b*) between fresh (24 hours *post mortem*) and aged (10 days *post mortem*) meat.
[5] CL_d = difference in cooking loss (CL) between fresh (24 hours *post mortem*) and aged (10 days *post mortem*) meat.
[6] SF_d = difference in shear force (SF) between fresh (24 hours *post mortem*) and aged (10 days *post mortem*) meat.
Mo = moisture; CP = crude protein; As= ash; Ch= cholesterol.

Overall, commercial *B. indicus* e *B. taurus* cattle sampled from typical finishing systems practiced in Brazil produced meat with: (a) pH means from 5.82 to 5.92, values above the range considered adequate (pH<5.8) for shelf-life maintenance (Mach et al., 2008); (b) means of L*, a* and b* color coordinates from 30.9 to 34.7, 16.5 to 20.3 and 3.9 to 5.7, respectively, which are considered within the normal range (38.51 > L* > 29.68, 29.27 > a* > 14.83, and 8.28 > b* > 3.40) by Abularach et al. (1998), (c) shear force means ranging from 7.4 to 8.8 kg in fresh samples and 5.4 to 5.8 kg in aged samples, which, for the fresh samples, are considered between moderately tender (<11.0 kg) and tender (<8.0 kg), according Bickerstaffe et al. (1997), and (d) intramuscular fat in LT with means between 3.0 to 7.7%. Our results for intramuscular fat in pasture-finished animals are within the range found in most European countries, whereas those for grain-finished animals are well above this range and also exceed those found in New Zealand and Argentina, approaching the fat content observed in the Wagyu breed (Garcia et al., 2008; Purchas & Zou, 2008).

When compared with FP, samples from FG animals had a much higher fat content (nearly 2.5 times higher), but lower moisture, crude protein and ash. Compared to pasture, the high energy of the grain-based diet determines a higher energy intake in FG animals, resulting in their higher meat fat content, which is in agreement with previous results

(French et al., 2001, Bruce et al., 2004, Realini et al., 2004). Fat content has been shown to be associated with meat quality traits, such as color (Mancini & Hunt, 2005), cooking loss and shear force (Bruce et al., 2004). In this study, fat was moderately correlated (Table 3) with pH (r = -0.29), meat lightness after ageing (r = 0.26), and redness in fresh samples (r = 0.25). Overall, animals receiving a higher energy diet are expected to produce meat with a higher fat content and increased glycogen reserves before slaughter, resulting in a lower final pH of meat (Muchenje et al., 2009). Furthermore, as fat content increases, the lighter color of fat may result in an increase in meat lightness, and the amount of oxygen-reactive myoglobin is also expected to increase, thus intensifying the redness of meat (Mancini & Hunt, 2005).

Differences between the *B. taurus* and *B. indicus* groups were not significant for meat moisture and crude protein, but fat content was higher in *B. indicus* by about 0.70%. This result is in agreement with Moreira et al. (2003), who reported higher levels of intramuscular fat in Nelore cattle, when compared with *B. indicus***B. taurus* crosses, but it is in contrast with reports by Crouse et al. (1989) and Wheeler et al. (1994), who found lower levels of fat or decreased marbling in *B. indicus* breeds and crosses. On the other hand, Whipple et al. (1990), O'Connor et al. (1997), Gonzalez et al. (2003) and Heinemann et al. (2003) did not find differences in marbling or intramuscular fat when comparing *B. taurus*, *B. indicus* and *B. taurus***B. indicus*. The results of this work indicate that, although finishing system has a major effect on meat fat content, genetic groups still have some influence, with leaner meat in *B. taurus* cattle. This is somewhat in contrast with the results reported by Crouse et al. (1989) and Wheeler et al. (1994), and could result from differences in fat deposition between the *B. indicus* breeds studied by those authors, which were Brahman and Sahiwal, whereas most of the *B. indicus* cattle raised in Brazil are of the Nelore, Tabapuã and Guzerá breeds.

For animals finished with grain, the level of cholesterol in meat was about twice as much in *B. indicus* when compared with *B. taurus*. Nevertheless, when they were finished on pasture, *B. taurus* had a slightly higher cholesterol content than *B. indicus*. Indeed, *B. taurus* cattle finished on grain had slightly less cholesterol than when finished in pasture, whereas *B. indicus* showed the opposite pattern. This result was not expected, and could represent a true genotype*environment interaction, reflecting the ability of *B. indicus* cattle to accumulate higher levels of cholesterol in energy-rich finishing diets. Moreira et al. (2003) compared cholesterol levels in Nelore and *B. taurus* crossed animals finished on pasture, and found lower, though non-significant, levels of cholesterol in Nelore, in agreement with the results of this work. On the other hand, the cholesterol level in meat was positively correlated with fat content in this study (r = 0.40; P<0.01), confirming the findings of Alfaia et al. (2007), who reported that meat with high intramuscular fat also has high cholesterol levels.

Finishing with supplementation resulted in meat with lower pH at 24 hours (difference of 0.10 pH units relative to FP animals), probably because of the higher availability of glycogen at the time of slaughter (Neath et al., 2007). A lower carcass pH in FG animals has also been reported by other authors, both in *B. taurus* (Nuernberg et al., 2005) and *B. indicus* (Bruce et al., 2004). In the present study, a small correlation was found between pH and cooking loss in aged meat (r = -0.23; P<0.01) but the association of pH with shear force was not significant, in contrast with the results of Muchenje et al. (2009), who reported strong correlations of pH with cooking loss (r = -0.79) and shear force (r = -0.58). In the data of this work, when analyzed within finishing system (results not shown), the correlations of pH with shear force in fresh and aged meat were similar (P>0.05), but the correlations with the change in shear force with ageing were -0.17 (P>0.05) in FG and 0.29 in FP (P<0.05). These results indicate that the reduction in shear force with ageing did not depend on pH in FG animals, whereas higher pH values were associated with greater reductions in shear force in FP. Beltrán et al. (1997) reported that meat with high final pH (>5.8) has a lower shear force, due to the higher activity of m-calpain and proteolysis of myofibrillar proteins at higher pH values, which would explain the relationship found in FP animals. The mean pH was similar in *B. indicus* and *B. taurus*, suggesting that the higher levels of pre-slaughter stress commonly reported for *B. indicus* (Silveira et al., 2006) do not seem to have a negative impact on meat pH.

In *B. taurus*, lightness of fresh and aged meat was similar in FG and FP animals, whereas in *B. indicus*, meat was lighter in FG than in FP (P<0.05), as commonly observed in Zebu cattle (Bruce et al., 2004). This pattern in *B. indicus* could be a consequence of their higher fat content, especially in FG, and it is confirmed by the positive correlation (r = 0.26, P<0.01) between fat content and 24-hour L*. It is interesting to observe in the results of this work that ageing caused meat to become significantly lighter in FG animals of both genetic groups, whereas in FP, the increase in lightness was non-significant in *B. taurus* and meat became darker with ageing in *B. indicus*. Possibly, the differences observed between treatments for lightness in fresh and aged meat may be attributed to differences in redox pigment stability due to oxidation (Mancini & Hunt, 2005). Lower color stability is associated with higher rates of poly-unsaturated

fatty acids (PUFA) and with secondary products of fat oxidation (Alderton et al., 2003). Typically, animals finished on pasture, when compared with those finished with grain, show higher amounts of PUFA (Wood et al., 2008). On the other hand, when *B. taurus* and *B. indicus* are compared, higher percentages of PUFA are found in *B. indicus*, both in intramuscular (Bressan et al., 2011) and subcutaneous (Huerta-Leidenz et al., 1993) fat. As PUFAs are of dietary origin and suffer extensive biohydrogenation, the higher deposition found in the meat of *B. indicus* was attributed to a decreased effectiveness in the biohydrogenation process (Bressan et al., 2011), possibly due to morphological and physiological differences between *B. taurus* and *B. indic*us.

Meat redness was significantly lower in FP in fresh meat, and ageing resulted in a similar decline in meat redness in both finishing systems. Differences in redness may be due to the stability of heme pigments (Faustman et al., 1999; Lynch & Faustman, 2000; Mancini & Hunt, 2005), and animals finished on pasture usually have higher amounts of poly-unsaturated fatty acids, which have lower levels of lipid stability (French et al., 2000, Descalzo et al., 2005). Therefore, animals from FP would be expected to have higher levels of oxidation of heme pigments, leading to a more tangible decline in redness with ageing, but this was not observed in our study, possibly because of the higher amount of carotenoids in the diet of FP animals (Dunne et al., 2009), which would contribute to lipid stability and meat color shelf-life. Mean redness of fresh and aged meat was similar for the two genetic groups, and the reduction of redness with ageing was also similar. These results suggest that the decline in the ability to form oxymyoglobin with the ageing of meat (Mancini & Hunt, 2005) is similar in *B. indicus* and *B. taurus*.

Yellowness of fresh meat was higher in *B. taurus* than in *B. indicus* when animals were finished in pasture, but no differences among genetic groups were observed in grain-finishing. However, in aged meat, yellowness was higher in *B. taurus* in both finishing systems. Yang et al. (2002) showed that the level of β-carotene (the major pigment responsible for the yellow color of fat in forage-finished animals) in plasma, muscle and adipose tissues is higher in pasture- than in grain-finished animals, and it increases with longer periods of grazing. Therefore, it can be expected that meat from pasture or forage-fed animals would tend to have higher yellowness (Kerth et al., 2007). However, this pattern was only observed in *B. taurus* animals, which had higher yellowness when finished on pasture, whereas the opposite was observed in *B. indicus*, with higher yellowness in grain-finished animals.

Neither finishing system nor genetic group had a significant effect on cooking loss of fresh or aged meat samples. In general, cooking loss did not change much with ageing, except in FG animals, where the difference between cooking loss in fresh and aged meat was significant, with an increase in aged meat. Bruce et al. (2004), comparing LT samples aged for 14 days, found higher losses in grain-finished than in pasture-finished Brahman animals. The cooking losses are associated with the water-holding capacity during application of external forces, such as cutting, heating, grinding or pressing (Zhang et al., 2005). Furthermore, the ability of meat to retain its water depends on ionic strength (pH), as well as on quantity and integrity of protein structure (Muchenje et al., 2009). In this study, the highest change in cooking loss with ageing was observed in FG samples, which were also those with lower mean pH (with a value closer to the iso-electric point of proteins), lower protein percentage (fewer available points to bind water and other peptide chains) and lower shear force in aged and fresh meat (suggesting an increase in protein degradation). Indeed, our results confirm that cooking loss is associated with pH ($r = -0.23$ for pH with cooking loss 10 days) but the association with shear force was opposite to the expected pattern, with a positive correlation between cooking loss and shear force ($r = 0.20$ for 24-hour CL with 24-hour SF, and $r = 0.20$ for 10-day CL with 10-day SF).

The shear force of the LT samples was higher in FP animals, both in fresh and aged meat, even though the difference was reduced by about one-half when aged samples were compared to fresh samples. Nevertheless, the drop in shear force with ageing did not differ significantly among finishing systems. No clear effect of finishing system on meat tenderness in beef has been demonstrated so far, with comparisons of shear force of meat from pasture-finishing versus grain-finishing being either non-significant (Bruce et al., 2004), in favour of grain-finishing (Dannenberger et al., 2006) or of pasture-finishing (French et al., 2000, Realini et al., 2004). In our results, the highest shear force in LT from cattle finished on pasture may have been due to increased collagen cross-linking, associated with increased exercise (Purslow, 2005). The decrease in meat toughness with ageing may have been caused by the weakening of myofibrillar protein and intramuscular connective tissue, through the action of endogenous enzymes (Koohmaraie et al., 2002).

The shear force value of LT samples was significantly higher in *B. indicus*, especially in fresh meat, in which the difference to *B. taurus* was nearly 1.4 kg, but this difference was reduced to about 0.7 kg after ageing. This result indicates that meat tenderness benefits more from ageing

in *B. indicus* than in *B. taurus*. This result was not expected, because it has been reported that *B. indicus* breeds have increased activity of calpastatin (Shackelford et al., 1991; O'Connor et al., 1997), which inhibits the calpain-induced proteolysis occurring with ageing (Koohmaraie et al., 2002), thus resulting in tougher meat in *B. indicus* (Wheeler et al., 2001). The results of this work do not support this idea. However, in this work, meat samples were kept frozen for 30 days before the ageing period, which could have affected the activity of the calpain-calpastatin complex. A reduction in calpastatin activity in frozen meat has been reported in cattle (Koohmaraie, 1990) and sheep (Duckett et al., 1998), but this pattern has not been confirmed in pigs, where m-calpain, μ-calpain and calpastatin seem to maintain their activity during frozen storage of meat (Kristensen et al., 2006). The reduction in calpastatin activity which is expected to occur in frozen beef could be more pronounced in *B. indicus* cattle, as they have increased calpastatin activity (O'Connor et al., 1997), and this may justify the higher reduction in shear force with ageing which was observed in *B. indicus* animals.

Conclusions

Finishing with supplementation enhances pH, color and meat tenderness, but causes a large increase in fat content in the two genetic groups evaluated, and in cholesterol content in *B. indicus*. Large differences are observed among genetic groups in shear force, with better tenderness in *B. taurus* than in *B. indicus*. Generally, ageing for 10 days improves the physical characteristics of the meat, including an increase in lightness and in yellowness in most cases, except for *B. indicus* under pasture-finishing, which has a decline in lightness and maintained yellowness. Meat tenderness improves with ageing in both genetic groups, more pronouncedly in *B. indicus*.

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