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Carcass characteristics and meat evaluation of Nelore cattle subjected to different antioxidant treatments

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ABSTRACT - Forty Nelore cattle were used to evaluate the effects of supplementation with different antioxidants on carcass characteristics and meat quality of feedlot cattle. Animals were fed *Brachiaria brizantha* hay and subjected to five treatments (control and four antioxidants: zinc, selenium, vitamin E, and selenium + vitamin E). After a 105-day feeding period, cattle were slaughtered. Tissue composition, as well as carcass proximate composition, color, tenderness, pH, and fatty acid profile were evaluated. Analysis of variance was carried out and means compared by Tukey test at 0.05 probability. The group fed selenium showed the lowest muscle amount (66.61 g/100 g) compared with the other antioxidants evaluated. There was no difference among treatments for bone, fat, and comestible portion percentages as well as muscle:bone, muscle: fat, and comestible portion:bone ratios, with mean values of 16.85 g/100 g, 14.70 g/100 g, 82.99 g/100 g, 4.06, 4.85, and 4.95, respectively. Neither brightness, red, or yellow contents of the meat nor carcass pH were affected by treatments. For tenderness and losses during thawing and cooking, there were no differences among treatments, with averages of 6.43 kgf cm^2, 3.22 g/100 g, and 21.15 g/100 g, respectively. Supplementation of Nelore cattle fed *Brachiaria brizantha* hay with antioxidants do not influence carcass characteristics or meat quality. However, vitamin E supplementation reduces the levels of omega 3 fatty acid, whereas supplementation with selenium + vitamin E promotes an increase in linoleic and palmitoleic acids and a decrease in myristoleic acid, making the supplementation feasible due to the beneficial effects provided by these acids.

Key Words: fatty acid, saponin, selenium, vitamin E, zinc

Introduction

Quality beef programs need to guarantee more than safe, nutritious, and tasty products to the costumer. There is a need for sustainable production, the promotion of human and animal well-being, forming a link between customer satisfaction and producer income, without harming the environment (Costa, 2002). There is also concern about human health, not only related to the sanitary quality of foods, but mainly in relation to the possible effects (harmful or beneficial) of certain foods or nutrients on the consumer health.

Beef quality is usually evaluated by sensory characteristics such as color, texture, tenderness, and palatability. However, other aspects are also relevant, such as fat content and fatty acid composition. Ruminant fat has a higher concentration of saturated fatty acid and less polyunsaturated:saturated ratio compared with non-ruminants, mainly due to the rumen biohydrogenation process of unsaturated fatty acids by microorganisms (French et al., 2003).

Antioxidants are substances that directly or indirectly protect cellular systems from the toxic effects caused by oxidative radicals (Halliwell, 1999). Antioxidants represent an alternative in preventing meat oxidation by delaying autoxidation processes, inhibiting free-radical formation during the initial stage of the oxidation reaction, by interrupting the propagation step, protecting the lipids present in the meat, and stabilizing the myoglobin molecules (O'Grady et al., 1996). However, in recent years, pressure by consumers has grown for the industry to adopt the use

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of natural antioxidants in replacement of synthetic ones (Hayes et al., 2009). Among the nutritional supplements with antioxidant effects, the most often used in cattle feed are zinc, selenium, and vitamin E (Baldin et al., 2013; Castilho et al., 2013).

Several factors are involved in the low productivity of the pasture-based cattle production system in the Brazilian Midwest. Intoxication of animals consuming this forage is frequently observed due to saponins. Removal of the saponins is not viable; so, the use of antioxidants to neutralize their effect on the animal organism may be a way to minimize their effects, improve animal health, and thus generate more beef with nutritional characteristics suitable for consumer market (Castilho et al., 2013). Therefore, this study aimed to evaluate the effects of supplementation with different antioxidants on carcass characteristics and meat quality of feedlot cattle fed *Brachiaria* hay.

Material and Methods

Animal care procedures throughout the study followed protocols approved by the Ethics Committee for Animal Use (CEUA) of the Universidade Federal de Goiás and was registered under case no. 360/2010.

Forty Nelore cattle aged 24-36 months were used. The animals were identified, dewormed, and distributed into five treatments: control *(Brachiaria brizantha* hay); *Brachiaria brizantha* hay + zinc supplementation with 600 mg animal^{-1} day^{-1} (zinc methionine); *Brachiaria brizantha* hay + supplementation with vitamin E, 1000 IU animal^{-1} day^{-1} (α-tocopherol acetate); *Brachiaria brizantha* hay + selenium supplementation with 10 mg animal^{-1} day^{-1} (sodium selenite); and *Brachiaria brizantha* hay supplementation with 1000 IU of vitamin E and 10 mg of selenium animal^{-1} day^{-1} (α-tocopherol acetate and sodium selenite), with eight animals per treatment (each animal representing a repetition). The guaranteed levels of the diets contained 50,000 IU/kg of vitamin E, as well as 120 mg/kg of zinc and 0.405 mg/kg of selenium. The selection of the antioxidant to be offered in each treatment was performed randomly and, thereafter, it was provided daily to the animals via oral administration, diluted in the concentrate.

The total duration of the study was 129 days, with 24 days for adaptation and 105 for the experiment. The animals were maintained in paddocks with troughs and drinkers. Animals were fed twice daily (08.00 and 15.00 h), with roughage (*Braquiaria brizantha* hay) and concentrate. The concentrate was formulated in accordance with NRC (2001) recommendations to meet an average daily gain of 0.770 kg and contained 340 g/kg crude protein and 710 g/kg total digestible nutrients. The concentrate ingredients were soybean meal, corn bran, and mineral mixture. The proportion used for forage:concentrate ratio was 70:30. The concentrate was offered individually, together with the antioxidant and only after the concentrate plus antioxidant total intake the hay was provided in the trough.

At the end of the feeding period, cattle were fasted for more than 24 h before slaughter and then were slaughtered at a commercial abattoir under federal inspection.

Carcasses were graded according to the parameters of the Brazilian Ministry of Agriculture, Livestock, and Supply. After 24 h in a cold room, the right halves of the carcasses were used to obtain the pH values. From the left half of each carcass, one section (HH) was extracted between the 11th and 13th ribs, which was wrapped in plastic bags and frozen for different analyses. The determination of muscle, bone, and fat percentage was performed by incising the *Longissimus dorsi* muscle, between the 11th and 12th vertebras. Subsequently, the *Longissimus dorsi* muscle was separated from the fat that covers it. Muscle, fat, and the remainder of the HH section were weighed separately. After weighing, the muscle was packed and frozen at –30 ºC for later evaluation.

The pH determination was performed by incising the *Longissimus dorsi* muscle between the 12th and 13th vertebra using a digital pH meter with a penetration probe (Hanna, model HI 8314). The device was calibrated with buffer solutions of pH 4.00 and 6.86. Electrode cleaning was performed with neutral detergent and distilled water after each reading.

Frozen samples of *Longissimus dorsi* muscle and HH were slowly thawed to determine the percentage of bone, muscle, and fat, as in Arboitte et al. (2011).

The proportion of muscle, fat, and bone of the carcass was estimated based on the proportions of these components in the HH section through the equations developed by Hankins and Howe (1946): Muscle = 16.08 + 0.80X; adipose tissue = 3.54 + 0.80X; and bones = 5.52 + 0.57X, in which X is the percentage of the HH section component validated previously for the cattle and production systems used in this study.

Longissimus dorsi muscle samples, previously minced and homogenized, were used for determination of dry matter, ash, and crude protein as in AOAC (1990), while the fat determinations were performed according to Folch et al. (1957).

The determination of the meat color was performed by CIEL*a*b* methodology using a BYK Gardner GmbH colorimeter (Wesel, Germany).

Losses on thawing and in the cooking process were determined in the same frozen samples of *Longissimus dorsi* muscle and were performed consecutively. To determine the meat water retention capacity, 2.5-cm thick steaks were obtained from the cranial portion of *Longissimus dorsi* muscle. The steaks were weighed frozen and then placed on racks and thawed under refrigeration at a temperature of 7 °C for 24 h. The steaks were reweighed for determination of water drip loss, expressed as percentage of initial weight as in Arboitte et al. (2011).

The shear force (tenderness of the meat) was determined in steaks baked for 24 h and then cooled. For determination of cooking loss and shear force (WBS) values, samples were weighed and then cooked in a plastic bag in a water bath until an internal temperature of 71 °C was achieved. After cooling to 7 °C, the samples were taken from the bags, dried with filter paper, and reweighed. The losses were expressed as percentage of initial weight.

Seven cylinders of 1/2 inch^2 area per steak, cut perpendicularly to the fiber at an angle of 45 °C and a diameter of 2 cm each, were used to determine the tenderness of meat by the shear force (kgf^2) using Warner-Bratzler Meat Shear equipment (Salter Brecknell® 2356X model), fitted with cutting blade with 1.016-mm thickness and a load speed of about 20 cm min^{-1} and load capacity of 25 kgf per cm^2. Average of all readings was considered after discarding the maximum and minimum values according to Arboitte et al. (2011).

For determination of lipid profile in total intramuscular fat content of *Longissimus dorsi* muscle samples, the lipids were first extracted using the Bligh and Dyer (1959) method; then, they were esterified according to Hatman and Lago (1973) and analyzed in a gas chromatograph coupled to a computer with a computer package equipped with a flame ionization detector and capillary polyethylene-glycol column (J&W DB-Wax), 30 m long by 0.25 mm diameter and filled with 0.25 mm, and the sample was injected at a split ratio of 1:10. The temperature of the injector and detector was 250 °C. Temperature gradient used for the separation of fatty acids esters was: 180 to 190 °C at 5 °C min^{-1}, 190 °C for 12 min, 190 to 215 °C at 3 °C min^{-1}, 215 °C to 240 °C at 5 °C min^{-1}, and 240 °C for 10 min. The carrier gas used was nitrogen in 1-mL min^{-1} flow. As a chromatographic standard, a mixture of fatty acids known as PUFA 2 (Sigma-Aldrich) was used. Fatty acid identification was carried out by comparing the retention time of the sampling fatty acids with the standard. Fatty acids were grouped as follows: saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), and unsaturated (UFA, including MUFA and PUFA). The following ratios were calculated: SFA:UFA, PUFA:SFA, and n6:n3.

The experimental design was completely randomized with five treatments and eight replications. The treatments were analyzed using the F test and the parameters with significant effect were compared by Tukey test at 0.05 probability. Statistical analyses were performed using SAS software (Statistical Analysis System, version 9.3). The mathematic model used was:

$$Yij = \mu + \tau i + b_1(IW - IW_m) + eij,$$

in which Yij represents the dependent variables; μ is the overall mean of the observations; τi is the fixed effect of dietary treatment; and eij is the random residual experimental error. The initial body weight (IW) was included in the model as a covariate, in which b_1 is the linear regression coefficient and IW_m is the mean initial body weight.

Results

In general, initial body weight did not affect carcass traits or fatty acid analyses. There was variation in the carcass muscle percentage according to the antioxidant used (Table 1). Selenium showed the lowest muscle percentage compared with the other antioxidants evaluated. However, there was no difference between treatments for bone, fat,

Table 1 - Average values of tissue and carcass composition of beef cattle supplemented with different antioxidants

Trait	Treatment					Mean	SEM	Pr>F	
	Control	Zinc	Selenium	Vitamin E	Selenium + vitamin E			Treatments	IBW
Muscle (g/100 g)	69.74a	67.51ab	66.61b	69.87a	67.72ab	68.29	0.39	0.0318	0.0080
Bone (g/100 g)	16.58	16.81	17.25	16.90	16.73	16.85	0.17	0.8155	0.5066
Fat (g/100 g)	13.61	15.56	15.83	13.05	15.43	14.70	0.45	0.2614	0.0795
Comestible portion (g/100 g)	83.35	83.06	82.46	82.92	83.17	82.99	0.24	0.8385	0.5738
Muscle:bone	4.2	4.01	3.87	4.16	4.06	4.06	0.05	0.3318	0.0563
Muscle:fat	5.48	4.41	4.32	5.45	4.58	4.85	0.18	0.1361	0.0348
Comestible portion:bone	5.05	4.96	4.81	4.92	5.01	4.95	0.06	0.8535	0.4635

SEM - standard error of the mean; IBW - covariate initial body weight; Pr>F - probability.
Different letters in the row differ by Tukey test (P<0.05).

and comestible portion percentages, as well as muscle: bone, muscle:fat, and comestible portion:bone ratios, with mean values of 16.85 g/100 g, 14.70 g/100 g, 82.99 g/100 g, 4.06, 4.85, and 4.95, respectively.

For meat chemical composition, no differences for the percentages of moisture, dry matter, ash, protein, and lipids were observed among treatments (Table 2), with mean values of 24.26 g/100 g dry matter, 1.36 g/100 g ash, 1.39 g/100 g fat, and 19.89 g/100 g protein.

Neither the basic color coordinates L*, a*, and b* in the meat (brightness, red, and yellow contents, respectively) nor carcass pH were affected by treatments (Table 3), with mean values of 29.29 of brightness and 6.31 of pH.

For *Longissimus dorsi* muscle tenderness measured by shear force, the ability to retain water during thawing and cooking, there were no differences between treatments (Table 4), with averages of 6.43 kgf cm^2, 3.22 g/100 g, and 21.15 g/100 g, respectively.

In the meat lipid profile of the beef cattle studied, 29 fatty acids were identified, 14 SFA, four MUFA, and 11 PUFA (Table 5).

The fatty acids with the highest concentrations included myristic (C140, 14.15 g/100 g), oleic (C18:1 n-9 cis/C18:1 n-9 trans, 13.73 g/100 g), palmitoleic (C16:1, 13.47 g/100 g), lauric (C12:0, 9.13 g/100 g), eicosapentaenoic (C20:5 n-3, 8.91 g/100 g), capric (C10:0, 8.43 g/100 g), and palmitic acids (C16:0, 8.01 g/100 g) (Table 5).

There was variation in the *Longissimus dorsi* fatty acid profile according to the antioxidant used. Control, zinc, and selenium treatments showed the highest levels of palmitic (C16:0) and stearic acids (C18:0) and lower levels of palmitoleic acid (C16:1). Higher amounts of palmitoleic (C16:1), heptadecenoic (C17:1), elaidic (C18:1 n-9 cis/C18:1 n-9 trans), linoleic (C18:2 n-6 cis/C18:2 n-6 trans 9), and DHA acids (C22:6 n-3/C24:1 n-9) and lower levels of palmitic (C16:0) and stearic acids (C18:0) were observed for vitamin E and selenium + vitamin E treatments (Table 5).

Table 2 - Average values for meat proximate composition of beef cattle supplemented with different antioxidants

Trait (g/100 g)	Treatment					Mean	SEM	Pr>F	
	Control	Zinc	Selenium	Vitamin E	Selenium + vitamin E			Treatments	IBW
Moisture	75.60	76.08	75.53	75.95	75.51	75.73	0.14	0.6543	0.8112
Total dry matter	24.39	23.91	24.46	24.05	24.49	24.26	0.14	0.6543	0.8112
Mineral matter	1.25	1.49	1.35	1.50	1.20	1.36	0.07	0.6059	0.2828
Mineral matter (g/100 g DM)	5.11	6.24	5.54	6.16	4.94	5.6	0.28	0.4746	0.2705
Ether extract	1.43	1.24	1.52	1.17	1.59	1.39	0.08	0.4513	0.2265
Crude protein	20.21	19.44	20.12	19.6	20.07	19.89	0.12	0.1626	0.1261

DM - dry matter; SEM - standard error of the mean; IBW - covariate initial body weight; Pr>F - probability.

Table 3 - Average values for meat color and carcass pH of beef cattle supplemented with different antioxidants

Trait	Treatment					Mean	SEM	Pr>F	
	Control	Zinc	Selenium	Vitamin E	Selenium + vitamin E			Treatments	IBW
L*	30.51	29.64	28.03	29.02	29.24	29.29	0.58	0.7483	0.3052
a*	2.69	3.32	3.03	3.18	1.56	2.76	0.32	0.4583	0.3359
b*	3.07	2.20	2.68	2.91	2.43	2.66	0.22	0.8894	0.0568
pH	6.38	6.32	6.32	6.22	6.31	6.31	0.04	0.9015	0.0682

L* - brightness; a* - red content; b* - yellow content; SEM - standard error of the mean; IBW - covariate initial body weight; Pr>F - probability.

Table 4 - Average values for thawing, cooking, and total losses and shear force of meat of beef cattle supplemented with different antioxidants

Trait	Treatment					Mean	SEM	Pr>F	
	Control	Zinc	Selenium	Vitamin E	Selenium + vitamin E			Treatments	IBW
Thawing loss (g/100 g)	2.67	2.66	3.58	3.43	3.8	3.22	0.39	0.8616	0.9133
Cooking loss (g/100 g)	19.59	23.44	20.53	22.19	19.99	21.15	1.34	0.8725	0.4464
Total loss (g/100 g)	21.61	25.45	23.31	24.85	23.22	23.69	1.35	0.9021	0.4634
Shear (kgf cm^2)	6.11	6.81	6.58	7.23	5.43	6.43	0.47	0.8014	0.1158

SEM - standard error of the mean; IBW - covariate initial body weight; Pr>F - probability.

Table 5 - Average values for composition of fatty acids (g/100 g) in *Longissimus dorsi* muscle of beef cattle supplemented with different antioxidants

Fatty acid	Usual nomenclature	Treatment					Mean	SEM	Pr>F	
		Control	Zinc	Selenium	Vitamin E	Selenium + vitamin E			Treatments	IBW
C6:0	Caproic acid	0.85	5.05	12.02	1.05	12.99	6.38	2.24	0.2707	0.0737
C10:0	Capric acid	11.79	4.81	6.06	7.14	12.33	8.43	2.12	0.7680	0.2279
C11:0	Hendecanoic acid	1.16	0	0.62	0	1.93	0.74	0.33	0.3263	0.6282
C12:0	Lauric acid	8.23	10.57	9.41	4.77	12.68	9.13	1.90	0.7480	0.6353
C13:0	Tridecanoic acid	1.01	0.85	0.65	0.65	1.40	0.91	0.29	0.9234	0.5514
C14:0	Myristic acid	15.32	21.67	19.49	6.37	7.90	14.15	2.87	0.3540	0.7219
C14:1	Myristoleic acid	8.56a	7.72a	6.88ab	2.01b	4.07ab	5.85	0.85	0.0478	0.1106
C15:0	Pentadecylic acid	0.38	0	0.24	0.08	0	0.14	0.08	0.6544	0.5744
C15:1	Pentadecenoic acid	1.85a	1.05ab	0.68ab	0.52ab	0b	0.82	0.24	0.1824	0.4256
C16:0	Palmitic acid	14.25a	11.79a	9.66ab	2.23c	3.74bc	8.01	1.26	0.0049	0.5668
C16:1	Palmitoleic acid	4.71c	3.43c	7.62bc	29.37a	22.25ab	13.47	2.97	0.0105	0.8433
C17:0	Margaric acid	0.82	0.78	0	0.19	0	0.35	0.22	0.6719	0.3289
C17:1	Heptadecenoic acid	0c	0c	0.39bc	1.81a	1.28ab	0.69	0.18	0.0012	0.8654
C18:0	Stearic acid	8.34ab	9.99a	4.72abc	0.06c	1.4bc	4.90	1.16	0.0312	0.3608
C18:1 *n-9 cis*/C18:1 *n-9 trans*	Oleic acid	4.76b	9.83b	7.48b	28.54a	18.04ab	13.73	2.57	0.0102	0.1700
C18:2 *n-6 cis*/C18:2 *n-6 trans 9*	Linoleic acid	0b	0b	0b	0.32a	0.19a	0.10	0.03	0.0010	0.5804
C18:3 *n-6*	Gamma-linolenic acid	1.61	1.17	3.80	0.16	4.10	2.17	0.76	0.4400	0.3308
C18:3 *n-3*	Linolenic acid	0	1.37	0.57	0.25	1.42	0.72	0.31	0.4929	0.7282
C20:1 *n-9*	Eicosenoic acid	0b	0b	0b	0.29a	0.09b	0.07	0.02	0.0001	0.6126
C20:2	Arachidic acid	3.27a	1.07b	0.26b	0.22b	0b	0.97	0.30	0.0005	0.0206
C20:3 *n-6*/C20:3 *n-3*	Homo-linolenic acid	0	0	0.19	0.17	0.15	0.11	0.04	0.3658	0.1466
C20:4 *n-6*	Arachidonic acid	0	0	0.21	0.39	0.80	0.28	0.16	0.5055	0.4637
C20:5 *n-3*	Eicosapentaenoic acid	13.06ab	8.80ab	13.95a	3.16b	5.55ab	8.91	1.57	0.1203	0.3673
C21:0	Heneicosanoic acid	0b	0b	0b	0.11a	0b	0.02	0.00	0.0001	0.0983
C22:0	Behenic acid	0	0	0.38	0.57	0.45	0.28	0.10	0.1591	0.1646
C23:0	Tricosanoic acid	0	0	0	0.08	0.06	0.03	0.01	0.1160	0.7996
C24:0	Lignoceric acid	0	0	0.67	1.09	0.75	0.50	0.16	0.1057	0.1752
C22:1 *n-9*	Erucic acid	0b	0b	0b	0.05a	0b	0.01	0.00	0.0005	0.4351
C22:6 *n-3*	Docosahexaenoic acid	0b	0b	0b	0.16a	0.05ab	0.05	0.01	0.0156	0.8212
Saturated		62.16a	65.53a	63.92a	24.5b	55.64a	54.35	4.07	0.0042	0.9672
Unsaturated		37.84ab	34.47b	42.07ab	67.46a	58.09ab	47.98	4.70	0.1214	0.7441
MUFA		15.12	12.20	15.58	33.72	27.60	20.84	2.74	0.0606	0.8353
PUFA		22.71	22.27	26.49	33.74	33.74	27.12	2.60	0.5449	0.4495
Saturated:unsaturated ratio		2.11	2.02	2.03	1.12	2.17	1.89	0.27	0.6844	0.6554
PUFA:SFA ratio		0.41b	0.35b	0.46b	5.19a	1.03b	1.49	0.40	<0.0001	0.7663
ω-3	Omega 3	13.06ab	10.17ab	14.53a	3.41b	6.97ab	9.63	1.56	0.1320	0.3294
ω-6	Omega 6	1.61	1.17	4.21	0.73	5.06	2.56	0.92	0.4960	0.3156
ω-6:ω-3 ratio	Omega 6:Omega 3 ratio	0.36	0.02	0.01	2.56	3.73	1.34	0.76	0.4591	0.4128

SEM - standard error of the mean; IBW - covariate initial body weight; Pr>F - probability; MUFA - monounsaturated fatty acids; PUFA - polyunsaturated fatty acids; SFA - saturated fatty acids.
Different letters in the row differ by Tukey test (P<0.05).

Discussion

The use of additives such as vitamin E, selenium, and Zinc is associated with improvements in meat quality, without an influence of carcass characteristics (Comparin et al., 2013). However, in this study, selenium supplementation produced carcass with lower muscle percentage compared with the other supplements evaluated.

As expected, the tissue found in greater proportion was muscle (68.29 g/100 g), followed by bone (16.85 g/100 g) and fat (14.70 g/100 g). These tissue proportions can be explained by the grazing system and were similar to those reported by several authors working with Nelore and their crossbreds fed *Brachiaria sp*., with or without supplementation of corn and wheat bran (Razook et al., 2002; Vaz et al., 2002; Ribeiro et al., 2004; Freitas et al., 2008; Souza et al., 2009).

According to Müller and Primo (1986), good nutrition is important in the reduction of the proportion of bone in the carcass. These authors observed that animals receiving better food level had lower bone percentage, justifying lower muscle development in animals that received poorer-quality feed. During animal growth, fat is the tissue that has a later development, but is deposited at all ages, when energy intake exceeds that amount required by the animal (Boggs and Merkel, 1981).

According to Arboitte et al. (2011), among the tissues that compose the carcass, muscle is the most important since

it is the most desired by the consumer. However, fat tissue exerts functions such as an energy reservoir, space filling between tissues, and thermal insulation (Arboitte et al., 2011); it also influences the taste, flavor, tenderness, and succulence of the meat (Costa et al., 2002), and so is analyzed by the consumer at the time of purchase. Therefore, carcass must provide maximum amount of muscle, minimum of bone, and an amount of fat that varies depending on consumer preference.

The proximate composition of the beef was similar between treatments and with values similar to those obtained by Lawler et al. (2004), Freitas et al. (2008), Razook et al. (2002), Rubiano et al. (2009), Souza et al. (2009), and Sestari et al. (2012), when working with Nelore cattle. The exception is ether extract content, which was lower, possibly due to the lower energy density of the diets used in this study compared with the aforementioned authors, who aimed at higher weight gain. Therefore, the lack of treatment effect on the chemical composition may be due to the similar energy intake in all the treatments associated with the physiological phase of the animal with similar energy requirements. According to Sestari et al. (2012), in general, the content of ash and crude protein of *Longissimus dorsi* has low variation for change in the animal diet, whereas fat (ether extract) shows greater variation (Williams et al., 1983).

Supplementation of beef cattle with selenium did not increase the percentage of ether extract in meat, corroborating Meirelles (2009) and Lawler et al. (2004).

Meat color is an important factor in marketing, with the consumer rejecting darker meat associated with older animals or poor meat preservation (Müller, 1987). According to Muchenje et al. (2009), the average brightness (29.29), redness (2.76), and yellowness (2.66) values obtained in this study are typical of dark meat. Also, Muchenje et al. (2009) observed that the ideal range for cattle meat brightness is between 33.2 and 41.0 and the ideals of redness and yellowness values should be between 11.1 and 23.6 and between 6.1 and 11.3, respectively.

Meat was expected to be less dark for animals of this age; however, factors such as age, physical activity performed by animals, amount of color pigments, fat content, and final pH influence meat brightness (Muchenje et al., 2009). Yet, Voisinet et al. (1997) found darker meat in cattle with more excitable temperament. Moreover, in this work, the animals used were not castrated, which, as described by Rodrigues and Andrade (2004), have meats with lower brightness compared with castrated animals; this is possibly due to the lower content of intramuscular fat and for the fasting period of more than 24 h prior to slaughter, which may have interfered with the pH and color of the meat. Meat brightness, redness, and yellowness levels are also influenced by the amount of water on the surface of the cut, as a consequence of water retention capacity (Purchas, 1990), as intracellular water accumulation favors the absorption of light. In this study, water retention was high and the amount of fat and red color pigment were low.

Cooke et al. (2004) reported that animals fed diets with higher concentrate proportions present lighter fat compared with animals receiving diets containing forage, due to the high levels of carotenoids present in the forage. This also explains the low color levels in this study, in which the animals were fed *Braquiaria* hay as a roughage source. According to Pinho et al. (2011), consumers prefer meat with white or cream fat color because the yellow color is associated with meat coming from older animals raised at pasture and so, would be less soft.

Brightness characteristics and meat color are also directly related to the pH value after carcass cooling (Fernandes et al., 2009). The darker meat and lower brightness, lower intensities of red, and yellow meats typically account for meats with high final pH (Muchenje et al., 2009) as observed in this study (6.31). High pH values were also obtained by Sestari et al. (2012) in Nelore cattle and Heinemann et al. (2003) in 60% of Nelore and Nelore × Limousin animals.

Normally, glycolysis develops slowly; the initial pH (0 h) around 7.0 falls to between 6.4 and 6.8 after 5 h post-mortem and to 5.5 to 5.9 after 24 h (Roça, 2000). Final pH values, considered as normal for beef cattle meat, are between 5.4 and 5.6. Intermediate pH values are considered above 5.6 and can result in increased water retention and shorter shelf life of the meat compared with pH values considered as normal (Li et al., 2014).

The high pre-slaughter fasting time (18 h) suffered by the animals may have caused stress and physical exhaustion of the animal and contributed to high pH obtained in this study. According to Field (1971) and Vaz and Restle (2000), non-castrated animals are more susceptible to pre-slaughter stress that affects muscle glycogen deposition and subsequently meat pH. Carcass pH reduction favors proteolytic enzyme release, important for increasing meat tenderness. In addition, the meat acidity significantly increases the shelf life of the product.

Lawrie (2005) stated that meat water retention capacity is directly linked to the amount of fat present in it, and especially, the speed of pH decrease during post-mortem glycolysis. In this study, as fat levels and pH values did not differ among treatments, the losses by thawing and cooking were also not affected by treatments, corroborating

Costa et al. (2002), Lawrie (2005), Igarasi et al. (2008), and Pedreira et al. (2003). As there is a relationship between muscles with more marbling and higher water retention (Saffle and Bratzler, 1959), it is important to differentiate the muscles for its ability to retain water, because this factor directly affects consumer acceptance characteristics of the meat before it is cooked, directly influencing succulence during chewing (Lawrie, 2005).

Shear force is a technique used to assess meat softness. A higher shear force value corresponds to greater force required to break the sample and, therefore, less tenderness (Arboitte et al., 2011), which is attributed to post-mortem proteolysis and increased calpastatin activity (Shackelford et al., 1994). In this study, the average shear force was not affected by treatments, with an average value of 6.43 kgf cm^2, being classified as tough, similar to that observed by Vaz et al. (2002) of 6.01 kgf cm^2. Low values of shear force obtained in this study may be linked to animal finishing, in which there is more contact with people, a factor that may minimize pre-slaughter stress, resulting in meat less prone to cold shortening (Restle et al., 2001).

The predominant fatty acids in the lipid profile were myristic (14.15 g/100 g), oleic (13.73 g/100 g), palmitoleic (13.47 g/100 g), and lauric acids (9.13 g/100 g), unlike those found by Menezes et al. (2009), Enser et al. (1996), Banskalieva et al. (2000), and Sanudo et al. (2000), with predominance of oleic, palmitic, and stearic acids, possibly due to the diet characteristics. According to French et al. (2003) and Mensink and Katan (1992), myristic acid may be an undesirable fatty acid because it is responsible for the increase in LDL cholesterol in the blood, since it has the potential to lift the plasma concentration of cholesterol four to six times in comparison with C16:0, when both are derived from natural fats. In the present study, this fatty acid accounted for the largest percentage of total fatty acids present in the meat.

The fatty acids of most interest to consumers are mainly linolenic (C18:3 n-3) and linoleic (C18:2 n-6), as they are essential in human nutrition and have a positive relationship with human health, e.g., they reduce blood cholesterol, are prostaglandin components (arachidonic acid), and precursors (linolenic acids) for the synthesis of many polyunsaturated fatty acids (Bressan et al., 2004). The higher n-6:n-3 ratio found in this experiment may be due to differences in diet composition between feeding periods, since fats supplied by green forage have a higher content of C18:3 fatty acid, the precursor of essential n-3 PUFA (Elmore et al., 2004).

The slaughter season and muscle type for the concentrations of some fatty acids, including C20:4 and C20:5, which could result from modifications of muscle metabolic type caused by adaptations to the different grazing periods, followed by changes in fatty acid composition (Alfaia et al., 2007) can explain the results found in this work.

The increased content of PUFA in the meat can be achieved by alterations in the animal diets (Bressan et al., 2004). However, the elevation of these fatty acids in large amounts can cause greater meat oxidative rancidity, which reduces its palatability, conservation and, consequently, its commercial value.

Supplementation with vitamin E reduced the myristoleic acid concentration in the meat, which is desirable because this polyunsaturated fatty acid is less wanted. Furthermore, supplementation with vitamin E and selenium + vitamin E increased concentrations of palmitoleic, heptadecenoic, docosahexaenoic, linoleic, and oleic acids, resulting in a meat with low hypercholesterolemic effect and better sensory quality (Melton et al., 1982).

Supplementation with vitamin E also decreased the saturated fatty acid and omega 3 concentrations in the meat.

Conclusions

Supplementation of Nelore beef cattle fed *Brachiaria brizantha* hay with antioxidants do not influence carcass characteristics or meat quality. However, vitamin E supplementation reduces the omega 3 levels, whereas supplementation with selenium + vitamin E promotes an increase in linoleic and palmitoleic acids and a reduction in myristoleic acid, justifying supplementation use due to the beneficial effects provided by these acids.

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