

# Increasing the level of supplementation improves weight gain and increases $\omega$ -6 fatty acid levels in the meat of dairy steers finished on tropical pasture

## O aumento do nível de suplementação melhora o ganho em peso e eleva os teores de ácidos graxos $\omega$ -6 da carne de novilhos terminados em pasto tropical

Maria Magna Silva Pereira<sup>1</sup>; Mateus de Melo Lisboa<sup>1</sup>; Fabiano Ferreira da Silva<sup>2</sup>; Geraldo Trindade Júnior<sup>2</sup>; Márcio dos Santos Pedreira<sup>2</sup>; Tarcísio Ribeiro Paixão<sup>3</sup>; João Wilian Dias Silva<sup>1</sup>; Thiago Luís Alves Campos de Araújo<sup>3</sup>; Dorgival Moraes de Lima Júnior<sup>3\*</sup>; Robério Rodrigues Silva<sup>2</sup>

### Highlights

We tested concentrate supplementation (3 or 6 g kg<sup>-1</sup> BW) in finishing steers. The intake of 6 g kg<sup>-1</sup> BW of supplement increases the weight gain of steers. Concentrate supplementation did not influence the carcass of the steers.

### Abstract

The objective of this study was to evaluate the effect of concentrate supplementation on intake, apparent digestibility, feeding behavior, performance, carcass traits, centesimal composition, and fatty acid profile of meat from Girolando steers finished on tropical pasture during the dry season. Twenty castrated Girolando steers, aged 24 ± 2 months and weighing 371 ± 13.02 kg, were distributed in a completely randomized design. The animals were kept under intermittent grazing on *Urochloa brizantha* cv. Marandu for 135 days on 7.0 ha, divided into 14 paddocks. The animals received concentrate supplement at 3 g kg<sup>-1</sup> or 6 g kg<sup>-1</sup> of body weight (BW). Crude protein intake increased by 38% (P<0.05), and non-fiber carbohydrate intake increased by 15% with the increase in supplementation from 3 to 6 g kg<sup>-1</sup> BW at finishing. Chewing time and the number of chews per cud were lower (P<0.05) in steers

<sup>1</sup> Animal Scientist, Drs. in Animal Science, with emphasis on Ruminant Production, Universidade do Sudoeste da Bahia, UESB, Itapetinga, BA, Brazil. E-mail: magnasp@hotmail.com; teteubahia@hotmail.com; tarcisoirun@hotmail.com; joaowiliand@yahoo.com

<sup>2</sup> Profs., Animal Science Undergraduate Program, UESB, Itapetinga, BA, Brazil. E-mail: ffsilvauesb@hotmail.com; geraldouesb@yahoo.com.br; mpedreira@uesb.edu.br; rrsilva.uesb@hotmail.com

<sup>3</sup> Profs., Postgraduate Program in Animal Production, Universidade Federal Rural do Semi-Árido, UFRSA, Mossoró, RN, Brazil. E-mail: thiagotor4@hotmail.com; juniorzootec@yahoo.com.br

\* Author for correspondence

supplemented at 6 g kg<sup>-1</sup> BW during finishing. Daily weight gain was 29% higher ( $P < 0.05$ ) in animals supplemented at 6 g kg<sup>-1</sup> BW. Increasing the supplementation level did not influence ( $P > 0.05$ ) the weight, yield, or carcass fatness parameters of the steers. The 6 g kg<sup>-1</sup> level resulted in meat with lower ( $P < 0.05$ ) levels of C15:0 and C14:1, as well as higher ( $P < 0.05$ ) proportions of n-6 fatty acids and a higher n-6:n-3 ratio. We recommend a concentrate supplementation level of 3 g kg<sup>-1</sup> BW for steers finished on tropical pasture.

**Key words:** Concentrate supplementation. Dairy calves for beef production. Fatty acids in beef. Girolando steers. Grazing cattle.

## Resumo

Objetivou-se avaliar o efeito da suplementação concentrada sobre o consumo, digestibilidade aparente, comportamento ingestivo, desempenho, características da carcaça, composição centesimal e perfil em ácidos graxos da carne de novilhos Girolando terminados em pasto tropical no período seco. Foram utilizados 20 novilhos Girolando castrados, com  $24 \pm 2$  meses e  $371 \pm 13,02$  kg de peso inicial, distribuídos em delineamento inteiramente casualizado. Os animais foram mantidos em pastejo intermitente de *Urochloa brizantha* cv. Marandu, por 135 dias, em 7,0 ha, sendo divididos em quatorze piquetes. Os animais receberam 3 g kg<sup>-1</sup> ou 6 g kg<sup>-1</sup> do peso corporal (PC) de suplemento concentrado. Houve aumento ( $P < 0,05$ ) de 38% para o consumo de proteína bruta e 15% para o consumo de carboidratos não-fibrosos dos bovinos com aumento de 3 para 6 g kg<sup>-1</sup> do PC de suplemento na terminação. O tempo de mastigação e o número de mastigações por bolo foram menores ( $P < 0,05$ ) para os novilhos suplementados com 6 g kg<sup>-1</sup> de PC durante a terminação. O ganho em peso diário foi 29% maior ( $P < 0,05$ ) para os animais suplementados com 6 g kg<sup>-1</sup> do PC. O aumento do nível de suplementação não influenciou ( $P > 0,05$ ) os parâmetros de peso, rendimento e engorduramento da carcaça dos novilhos. O nível de 6 g kg<sup>-1</sup> promoveu carne com menores ( $P < 0,05$ ) teores de C15:0 e C14:1 e maiores ( $P < 0,05$ ) proporções de ácidos graxos n-6 e maior relação n-6:n-3. Recomendamos o nível de suplementação de 3 g kg<sup>-1</sup> do peso corporal de concentrado para novilhos terminados em pasto tropical.

**Palavras-chave:** Ácidos graxos na carne bovina. Bovinos em pastejo. Bezerro leiteiro para corte. Girolando. Suplementação em pasto.

## Introduction

Beef production from pasture-raised animals has several notable characteristics, including lower production costs per kilogram (Tsakiridis et al., 2024) and higher levels of polyunsaturated fatty acids in the meat (Carrillo et al., 2021). However, variations in forage production and the standardization of carcass quality remain challenges for pasture-fed beef production systems,

especially in tropical areas (Greenwood, 2021).

Supplementing grazing cattle with concentrate feedstuffs (i.e., grains and by-products) increases their nutritional intake, optimizing pasture nutrient utilization, enhancing performance, and improving carcass quality (Barroso et al., 2024, 2025). However, the literature reports significant variation in the effects of supplementation, depending on the supplementation level,

type of supplement, and pasture conditions (Barbero et al., 2021). Specifically regarding supplementation levels, a gradient of responses has been observed, with a general tendency toward higher carcass weights and increased saturated fat content in meat for animals finished with higher levels of concentrate supplementation (Nogoy et al., 2022; Rodrigo, 2024). On the other hand, low supplement levels (1 g kg<sup>-1</sup> and 3 g kg<sup>-1</sup> of body weight) appear to improve weight gain in cattle without significantly altering the fatty acid composition of their meat (Torrecilhas et al., 2021; Cediél-Devia et al., 2024).

In addition to supplementation levels, supplement composition influences the animals' response to supplementation, leading to the classification of supplements as "protein", "energy", or "protein-energy", which are widely used terms in Brazil (Detmann et al., 2014; Cardoso et al., 2020). Additionally, different bovine genotypes may exhibit distinct responses to supplementation levels and finishing intensification (Simioni et al., 2021), making it inconsistent to extrapolate results obtained with meat-specialized genotypes to steers from dairy herds, for example.

Due to the heterogeneity of responses reported in the literature (Silva et al., 2009; Almeida et al., 2022) and the limited number of studies on moderate supplementation levels (3 g kg<sup>-1</sup> to 6 g kg<sup>-1</sup> of BW), we hypothesized that Girolando steers finished on tropical pasture and supplemented with moderate levels (3 g kg<sup>-1</sup> or 6 g kg<sup>-1</sup> of BW) of the same composition would exhibit improved performance and carcass weight without changes in the fatty acid composition of the meat. Therefore, this study aimed to evaluate the effect of moderate supplementation

levels (3 g kg<sup>-1</sup> to 6 g kg<sup>-1</sup> of BW) on intake, apparent digestibility, feeding behavior, performance, carcass traits, centesimal meat composition, and the fatty acid profile of meat from Girolando steers finished on *Urochloa brizantha* cv. Marandu pasture during the dry season.

## Material and Methods

All experimental procedures complied with the Ethics Committee on Animal Use (license 141/2016, Ethics Committee on Animal Use/Southwestern Bahia State University, UESB, Bahia, Brazil).

### *Location, animals, and experimental treatments*

The experiment was conducted in the municipality of Ribeirão do Largo, Bahia, Brazil, located at 15° 26' 46" south latitude and 40° 44' 24" west longitude, at an altitude of 800 m. Twenty castrated Girolando steers (½ Holstein + ½ Gir) with an average age of 24 ± 2 months and an average initial body weight of 371 ± 13.02 kg were used. The animals were treated for ecto- and endoparasites (Dectomax®, Zoetis, New Jersey, USA) and vaccinated against foot-and-mouth disease (Ourovac® Aftosa, Ouro Fino, São Paulo, Brazil). The experimental period lasted 135 days, including 14 days for animal adaptation to the experimental management.

The animals were kept under intermittent grazing on *Urochloa brizantha* cv. Marandu in a total area of 7 ha, divided into fourteen 0.5 ha paddocks. To minimize the influence of biomass variation among paddocks, the animals remained in each

paddock for seven days before being randomly moved to another, following a pre-established rotation. The animals were subjected to two supplementation levels: 3 g kg<sup>-1</sup> or 6 g kg<sup>-1</sup> of body weight in concentrate

supplement per day, with 10 replicates per level. The supplements were formulated to meet the gain requirements of 0.5 kg day<sup>-1</sup> (National Research Council [NRC], 2016) (Table 1).

**Table 1**  
**Proportion of supplement ingredients and chemical composition and fatty acid profile of the supplement and experimental pasture**

		Supplement
Grain corn (%)		45.5
Soybean meal (%)		45.5
Urea + AS <sup>1</sup> (%)		5.0
Mineral mixture <sup>2</sup> (%)		4.0
Chemical composition	<i>Urochloa brizantha</i> <sup>3</sup>	
Dry matter (g kg <sup>-1</sup> as fed)	258.8	895.6
Crude protein (g kg <sup>-1</sup> DM)	83.0	351.6
Ether extract (g kg <sup>-1</sup> DM)	22.0	27.8
NDFap <sup>4</sup> (g kg <sup>-1</sup> DM)	606.2	112.5
Ash (g kg <sup>-1</sup> DM)	73.2	102.4
Non-fibrous carbohydrates (g kg <sup>-1</sup> DM)	215.6	405.7
TDN <sup>5</sup> (g kg <sup>-1</sup> DM)	549.7	617.7
Fatty acid composition (g 100 <sup>-1</sup> g)		
C12:00	0.00	0.46
C14:00	0.06	0.61
C15:00	0.01	0.17
C16:00	15.66	19.38
C16:01	0.09	0.00
C17:00	0.14	0.27
C17:01	0.04	0.05
C18:00	3.53	2.23
C18:1n-9t	0.06	0.01
C18:1n-9c	28.16	3.84
C18:2n-6t	0.08	0.11
C18:2n-6c	48.93	17.09
C18:3n-3	0.00	38.67
C20:00	2.09	1.15
C20:01	0.30	0.00

continue...

contuation...

C20:02	0.01	0.91
C20:3n-3	0.00	2.42
C21:00	0.00	0.10
C22:00	0.41	1.40
C22:1n-9c	0.00	3.64
C23:00	0.06	0.00
C24:00	0.27	1.56
EPA <sup>6</sup>	0.00	4.71

<sup>1</sup>Urea + Ammonium sulfate in a 9:1 ratio; <sup>2</sup>Provides per kilogram: Calcium 235 g; phosphorus 160 g; magnesium 16 g; sulfur 12 g; cobalt 150 mg; copper 1600 mg; iodine 190 mg; manganese 1400 mg; iron 100 mg; selenium 32 mg; zinc 600 mg; 1120 mg; fluorine (maximum) 16000 mg; <sup>3</sup>Simulated grazing; <sup>4</sup>Neutral detergent insoluble fiber corrected for ash and protein; <sup>5</sup>Total digestible nutrients; <sup>6</sup>Eicosapentaenoic acid.

Supplementation was provided daily at 10h:00min in collective plastic troughs with double access, uncovered, and with a linear space of 80 cm animal<sup>-1</sup>. The animals were distributed in a completely randomized design with two treatments and ten replicates per treatment.

#### *Forage evaluation and characterization*

The pasture was evaluated every 28 days (Table 2). To estimate the dry matter availability of each paddock, 12 samples

were collected by cutting at ground level using a 0.25 m<sup>2</sup> quadrat on the first day of each experimental period (Haydock & Shaw, 1975). The forage samples were weighed on a digital scale ( $\pm 5$  g precision) and mixed to form a composite sample for the paddocks. Aliquots were taken to estimate the dry matter availability of pasture components and to determine the forage accumulation rate. After manually separating pasture components (leaf blade, stem, and dead material), individual samples were frozen for chemical composition analysis.

**Table 2**  
**Pasture parameters of *Urochloa brizantha* cv. Marandu during the dry season**

Parameter (kg ha <sup>-1</sup> )	
Total dry matter availability	3,804
Potentially digestible dry matter availability	3,049
Green dry matter availability	2,093
Leaf dry matter availability	732
Stem dry matter availability	1361
Dead dry matter availability	1712
Stocking rate (AU <sup>1</sup> ha <sup>-1</sup> )	2.80
Forage accumulation rate (kg DM <sup>2</sup> ha day <sup>-1</sup> )	26
Forage allowance (kg DM <sup>2</sup> 100kg BW <sup>3</sup> day <sup>-1</sup> )	10.77

<sup>1</sup> Animal unit; <sup>2</sup> Dry matter; <sup>3</sup> Body weight.

Estimates of residual dry matter biomass were conducted in both paddocks using the double sampling method (Wilm et al., 1944), following the equation proposed by Gardner (1986). To estimate biomass accumulation over time, two paddocks were left ungrazed for 28 days to serve as excluders. Dry matter (DM) accumulation and forage allowance during different experimental periods were calculated based on the daily accumulation rate and the number of days in the period (Campbell, 1966). The estimation of potentially digestible dry matter in the pasture followed the methodology described by Detmann et al. (2016). The availability of potentially digestible DM was calculated as the product of DM availability (kg ha<sup>-1</sup>) and the potentially digestible DM content (%) in the pasture.

#### *Intake of pasture and supplement and apparent digestibility of the diet*

Estimates of fecal production, intake, and digestibility were conducted on the 68th day of the experimental period. To estimate fecal production, purified and enriched lignin (LIPE®) was used as an external marker, administered daily at 7h:00min in the morning, with one capsule per animal in a single dose for 12 days. The first seven days were allocated for adaptation and regulation of the marker's excretion flow, while the last five days were designated for fecal collection. Feces were collected once daily in the paddocks to prevent contamination, following a pre-established schedule: 8h:00min (1st day), 10h:00min (2nd day), 12h:00min (3rd day), 14h:00min (4th day), and 16h:00min (5th day), thus forming composite fecal samples for each animal. The collected feces were stored in a freezer at -10 °C.

Samples were pre-dried and ground using a knife mill (1- and 2-mm sieves) for subsequent analysis. Fecal production was estimated by determining the LIPE® content in feces, following the methodology proposed by Saliba & Rodriguez (2009).

Dry matter (DM) intake of the concentrate was estimated using titanium dioxide as an external marker. It was supplied at a dose of 11 g per animal, mixed with the concentrate, for eight days, following the procedure described by Titgemeyer et al. (2001) and the same fecal collection scheme used to estimate fecal production. The determination of titanium dioxide concentration was performed according to the INCT-CA M-007/1 methodology (Detmann et al., 2012). Individual concentrate intake was estimated by dividing the total excretion of titanium dioxide by its respective concentration in the concentrate.

Voluntary roughage intake was estimated using indigestible neutral detergent insoluble fiber (iNDF) as an internal marker. This was obtained after ruminal incubation for 240 h (Casali et al., 2008) from 0.5 g of feed, Orts, and fecal samples, in duplicate, using nonwoven fabric ("TNT") bags (100 g m<sup>-2</sup> grammage, 5 × 5 cm). The incubated residues were washed, dried in a forced-air oven, and subjected to neutral detergent extraction to determine iNDF, following the INCT-CA F-009/1 methodology (Detmann et al., 2012).

Total DM intake was calculated as follows:

$$\text{Total DMI (kg day}^{-1}\text{)} = \{[(\text{FE} \times \text{CMF}) - \text{MS}] + \text{SDMI}\} / \text{CMR},$$

where FE = fecal excretion (kg day<sup>-1</sup>), obtained using titanium dioxide; CMF = concentration of the marker in feces (kg kg<sup>-1</sup>); MS = quantity of the marker present in the concentrate supplement; SDMI = concentrate supplement DM intake; and CMR = concentration of the marker in the roughage (kg kg<sup>-1</sup>). Forage samples from the simulated grazing were obtained based on the observed intake of the experimental animals, as per Johnson (1978).

#### *Laboratory analyses of forage, supplement, and feces*

The concentrate, forage, and fecal samples were pre-dried and ground in a Wiley knife mill, using a 1 mm sieve for chemical analyses and a 2 mm sieve for digestibility analyses. Feed and fecal samples were analyzed for dry matter (method 934.01), mineral matter (method 942.05), crude protein (method 984.13), and ether extract (method 920.39), following Association of Official Analytical Chemists [AOAC] (2019) procedures. Analyses of neutral detergent fiber corrected for ash and protein (methods INCT-CA F-002/1, INCT-CA M-002/1, and INCT-CA N-004/1), acid detergent fiber (method INCT-CA F-004/1), and lignin (method INCT-CA F-005/1) were conducted as described by Detmann et al. (2012). The non-fibrous carbohydrate content corrected for ash and protein (NFCap) in forage and feces, as well as the total digestible nutrient content, were calculated using the equation proposed by Weiss (1999). Lipid extraction for concentrate and forage analysis followed the methodology of Folch et al. (1957).

### *Feeding behavior*

Feeding behavior evaluations were conducted on the 73rd experimental day, with observations recorded every 5 min following the methodology of Silva et al. (2006). Evaluations lasted for 48 h and were divided into four six-hour periods: morning: 06h:05min to 12h:00min; afternoon: 12h:05min to 18h:00min; evening: 18h:05min to 00h:00min; and dawn: 00h:05min to 06h:00min. Two trained observers were assigned to monitor each supplementation level, using binoculars to minimize disturbance to the animals. Digital stopwatches were used to record the time spent on each activity. For night-time observations, observers used flashlights to facilitate data collection.

The behavioral variables observed included grazing time, rumination time, idle time, and time spent feeding at the trough. From the collected data, tabulation and calculations were performed, including feeding and rumination times per unit of DM and NDF intake ( $\text{min kg}^{-1}$  DM or NDF). Total feeding time (TFT) and total chewing time (TCT) were determined using the following equations:

$$\text{TFT} = \text{Grazing time} + \text{Time spent feeding at the trough};$$

$$\text{TCT} = \text{Grazing time} + \text{Rumination time} + \text{Time spent feeding at the trough}.$$

A trained observer recorded the number of rumination chews and the time spent ruminating each ruminal cud for each animal by observing three ruminal cuds during three different periods of the day, following the methodology of Bürger et al. (2000). The number of daily cuds was

calculated by dividing the total rumination time by the average time spent ruminating each cud.

The discretization of the time series was performed directly in the data collection spreadsheets by counting the discrete bouts of grazing, rumination, idleness, and feeding at the trough. The average duration of each discrete bout was obtained by dividing the daily duration of each activity by the number of discrete bouts of the same activity, as described by Silva et al. (2006). Feeding and rumination efficiency, expressed in  $\text{g DM h}^{-1}$  and  $\text{g NDF h}^{-1}$ , was calculated by dividing the average daily intake of DM and NDF by the total time spent feeding and/or ruminating within 24 h, respectively. The biting rate for each supplementation type was estimated based on the time taken by an animal to perform 20 bites. Bite mass was calculated by dividing the daily forage intake by the total number of bites per day. Observations of bite and swallow behavior were conducted six times per day, with three evaluations in the morning and three in the afternoon, following the methodology of Baggio et al. (2009). These observations were also used to determine the total number of bites per day, obtained by multiplying biting rate by grazing time.

### *Animal performance and carcass traits*

Weighings were performed every 28 days, following a 12-h fast, to adjust the supplement supply according to body weight. Total weight gain and average daily gain (ADG) were calculated as the difference between final body weight (BW) and initial

body weight (IBW), divided by the duration of the experimental period in days. Feed efficiency (FE) was determined using the following equation:  $FE = (ADG, \text{kg d}^{-1}) / (DMI, \text{kg d}^{-1})$ .

After 135 days of finishing, the cattle underwent a 12-h fast, were weighed, and transported by road to the slaughterhouse. Following a six-hour rest period, they were slaughtered in accordance with current legislation (Regulamento da Inspeção Industrial e Sanitária de Produtos de Origem Animal [RIISPOA], 2017). Each animal's hot carcass was weighed and then sawn. Hot carcass yield was calculated as the ratio of hot carcass weight to body weight at slaughter. Subsequently, the right half of each carcass was placed in a cold chamber maintained at 2 °C for 24 h. After cooling, fat thickness was measured at three equidistant points using a precision caliper, in the region of the cut between the 12th and 13th ribs, over the Longissimus dorsi muscle.

#### *Proximate composition and fatty acid profile of the Longissimus dorsi muscle*

A section of the Longissimus dorsi muscle was removed from the right half of the carcass, between the 12th and 13th ribs. To prevent freezer burns, the muscles were first wrapped in plastic film, followed by aluminum foil, and then placed in labeled plastic bags, identifying the animal and treatment. The samples were immediately stored at -10 °C until laboratory analyses.

For chemical analysis, the samples were thawed at room temperature, the covering fat was removed, and the muscle

was ground for determination of moisture, ash, and crude protein contents using AOAC methodology. Total lipid content was assessed following the method adapted from Bligh & Dyer (1959). The transesterification of triacylglycerols to obtain fatty acid methyl esters was performed according to International Organization for Standardization [ISO] (1978). The methyl ester samples were stored in Eppendorf tubes at -18 °C for later chromatographic analysis. Fatty acid methyl esters were analyzed by gas chromatography using a Thermo-Finnigan apparatus equipped with a flame ionization detector and a BPX-70 fused silica capillary column (120 m, 0.25 mm i.d.). The carrier gas (N<sub>2</sub>) flow rate was 6.5 mL min<sup>-1</sup>, with an auxiliary N<sub>2</sub> flow rate of 30 mL min<sup>-1</sup>. The flame gases (H<sub>2</sub> and synthetic air) had flow rates of 30 mL min<sup>-1</sup> and 350 mL min<sup>-1</sup>, respectively. The sample split ratio was 90:10. The injector and detector temperatures were set at 250 °C and 280 °C, respectively. The total analysis time was 55 min, programmed in four temperature ramps, starting at 140 °C and reaching a final temperature of 238 °C. The injection volume was 1.2 µL, and peak areas were determined by the normalization method using Chrom Quest 4.1 software.

The quantification of fatty acids in the Longissimus dorsi muscle was determined by calculating the percentage area of each chromatographic peak. Each peak corresponded to a fatty acid identified with the Sigma fatty acid methyl ester standards (USA) and was verified by its equivalent chain length. The levels of saturated fatty acids (SFA) were calculated by summing lauric (C12:0), myristic (C14:0), pentacyclic (C15:0), palmitic (C16:0), margaric

(C17:0), stearic (C18:0), arachidic (C20:0), hencosanoic (C21:00), and behenic (C22:0) acids. The levels of monounsaturated fatty acids (MUFA) were determined by summing myristoleic (C14:1), pentadecenoic (C15:01), palmitoleic (C16:01), 8-heptadecenoic (C17:01), elaidic (C18:1n9t), oleic (C18:1n9c), vaccenic (C18:1n7c), gadoleic (C20:01), and erucic (C22:1n-9) acids. For polyunsaturated fatty acids (PUFA), the following acids were summed: linoleic (C18:2n6),  $\gamma$ -linolenic (C18:3n-6), linolenic (C18:3n-3), conjugated linoleic cis-9trans-11 (CLAc9t11), conjugated linoleic (CLA t10c12), di-homo  $\gamma$ -linolenic (C20:3n-6), di-homo-( $\alpha$ )linolenic (C20:3N-3), arachidonic (C20:4n-6), docosadienoic (C22:2n-6), eicosapentaenoic (EPA 20:5N-3), and docosahexaenoic – DHA (22:6n-3). The levels of omega-6 (n-6) and omega-3 (n-3) fatty acids were obtained by summing all acids that belong to each family. The n-6:n-3 ratio was calculated by dividing the sum of n-6 fatty acids by the sum of n-3 fatty acids, and the ratio of polyunsaturated to saturated fatty acids (PUFA:SFA) was determined in a similar manner.

### Statistical analyses

The studied variables were analyzed statistically using analysis of variance and the F test at a 0.05 probability level, employing the Universidade Federal de Viçosa [UFV] (2001). The statistical model used was:

$$Y_{ijk} = \mu + T_i + E_{ijk}$$

where;  $Y_{ijk}$  - observed value of the variable;  $\mu$  - general constant;  $T_i$  - effect of supplement type  $i$ ; and  $E_{ijk}$  - error associated with each observation.

### Results

Total dry matter (DM) and pasture intake by steers were not influenced ( $P > 0.05$ ) by the supplementation level. However, there was a 38% increase ( $P < 0.05$ ) in crude protein (CP) intake and a 14.7% increase in non-fibrous carbohydrate (NFC) intake when the supplementation level increased from 3 to 6 g kg<sup>-1</sup> BW during finishing. No effect ( $P > 0.05$ ) of supplementation level was observed on the apparent digestibility of DM, organic matter (OM), CP, NFC, or neutral detergent fiber (NDFap) in the steers' diet (Table 3).

**Table 3**

**Nutrient intake and apparent digestibility of the diet by steers supplemented and finished on tropical pasture (*Urochloa brizantha* cv. Marandu) during the dry season of the year**

	Supplementation level		SDM <sup>2</sup>	P-value <sup>3</sup>
	3 g kg <sup>-1</sup> of BW <sup>1</sup>	6 g kg <sup>-1</sup> of BW <sup>1</sup>		
Intake (kg day <sup>-1</sup> )				
Pasture dry matter	6.73	5.94	1.097	0.099
Total dry matter	8.03	8.57	1.210	0.302
Total dry matter (% of BW)	2.05	2.11	0.310	0.655
Organic matter	7.40	7.84	1.116	0.355
Crude protein	0.92	1.27	0.146	0.000
Ether extract	0.19	0.21	0.028	0.133
NDFap <sup>4</sup>	4.98	4.87	0.772	0.729
NFC <sup>5</sup>	1.29	1.48	0.192	0.032
TDN <sup>6</sup>	5.64	6.06	1.068	0.355
Apparent digestibility (%)				
Dry matter	71.22	71.33	4.832	0.956
Organic matter	73.67	73.95	4.443	0.880
Crude protein	84.75	86.78	5.660	0.400
Ether extract	75.72	77.30	5.638	0.307
NDFap <sup>4</sup>	74.33	72.71	5.006	0.449

<sup>1</sup> Body weight; <sup>2</sup> Standard deviation of the mean; <sup>3</sup> Significant at the 0.05 probability level; <sup>4</sup> Neutral detergent insoluble fiber corrected for ash and protein; <sup>5</sup> Non-fibrous carbohydrates; <sup>6</sup> Total digestible nutrients.

Increasing the supplementation level of steers did not influence ( $P > 0.05$ ) the time spent on grazing, idleness, rumination, chewing, or total feeding activities. However,

steers supplemented with 6 g kg<sup>-1</sup> BW during finishing exhibited reduced chewing time and a lower number of chews per cud (Table 4).

**Table 4**  
**Feeding behavior of steers supplemented and finished on tropical pasture (*Urochloa brizantha* cv. Marandu) during the dry season of the year**

	Supplementation level		SDM <sup>2</sup>	P-value <sup>3</sup>
	3 g kg <sup>-1</sup> of BW <sup>1</sup>	6 g kg <sup>-1</sup> of BW <sup>1</sup>		
Grazing time (min day <sup>-1</sup> )	420.25	422.00	66.411	0.930
Idle time (min day <sup>-1</sup> )	609.75	584.25	76.416	0.291
Rumination time (min day <sup>-1</sup> )	385.50	356.75	48.765	0.202
Time at trough (min day <sup>-1</sup> )	24.50	49.50	10.778	0.000
Total chewing time (min day <sup>-1</sup> )	830.25	828.25	85.412	0.931
Total feeding time (min day <sup>-1</sup> )	444.75	471.50	63.221	0.182
Biting rate (n s <sup>-1</sup> )	0.73	0.68	0.105	0.131
Bite mass (g DM <sup>-1</sup> 4)	0.49	0.52	0.146	0.142
Bites per swallow (n)	23.90	24.64	3.218	0.464
Biting time (s)	34.05	37.20	7.620	0.195
Number of bites (n day <sup>-1</sup> )	18823.78	17249.78	4078.116	0.235
Number of cuds (n day <sup>-1</sup> )	426.16	449.34	95.911	0.440
Time Bite <sup>-1</sup> (s)	54.90	48.29	6.217	0.001
Chews Cud <sup>-1</sup> (n)	50.11	43.13	7.151	0.003
Feeding efficiency (kg DM <sup>4</sup> h <sup>-1</sup> )	1.22	1.23	0.286	0.910
Feeding efficiency (kg NDFap <sup>5</sup> h <sup>-1</sup> )	0.760	0.707	0.179	0.355
Rumination efficiency (kg DM <sup>4</sup> h <sup>-1</sup> )	1.39	1.50	0.527	0.499
Rumination efficiency (kg NDFap <sup>5</sup> h <sup>-1</sup> )	0.863	0.861	0.326	0.999

<sup>1</sup> Body weight; <sup>2</sup> Standard deviation of the mean; <sup>3</sup> Significant at the 0.05 probability level; <sup>4</sup> Dry matter; <sup>5</sup> Neutral detergent fiber corrected for ash and protein

Final body weight was not affected (P>0.05) by the supplementation level at finishing. However, total and daily weight gains

were 29% higher in animals supplemented with 6 g kg<sup>-1</sup> BW compared to those receiving 3 g kg<sup>-1</sup> BW (Table 5).

**Table 5**  
**Performance, carcass traits, and meat composition (*Longissimus dorsi*) of steers supplemented and finished on tropical pasture (*Urochloa brizantha* cv. Marandu) during the dry season of the year**

	Supplementation level		SDM <sup>2</sup>	P-value <sup>3</sup>
	3 g kg <sup>-1</sup> of BW <sup>1</sup>	6 g kg <sup>-1</sup> of BW <sup>1</sup>		
Initial body weight (kg)	369.08	369.27	48.989	0.999
Final body weight (kg)	425.33	442.00	57.807	0.497
Daily weight gain (kg day <sup>-1</sup> )	0.42	0.54	0.110	0.014
Total weight gain (kg)	56.25	72.72	14.928	0.014
Feed efficiency (kg kg <sup>-1</sup> )	5.28	6.39	1.524	0.095
Hot carcass weight (kg)	213.95	220.27	28.267	0.598
Carcass yield (%)	50.36	49.83	1.492	0.406
SFT <sup>4</sup> (mm)	2.96	2.42	0.773	0.110
Moisture (%)	72.03	71.82	12.809	0.377
Ash (%)	1.40	1.33	0.3170	0.606
Crude protein (%)	22.92	23.48	48.989	0.545
Crude fat (%)	1.39	1.41	57.807	0.835

<sup>1</sup> Body weight; <sup>2</sup> Standard deviation of the mean; <sup>3</sup> Significant at the 0.05 probability level; <sup>4</sup> Subcutaneous fat thickness.

Increasing supplementation from 3 g kg<sup>-1</sup> to 6 g kg<sup>-1</sup> BW during finishing did not affect ( $P>0.05$ ) carcass weight, yield, or fat content. No effects ( $P>0.05$ ) of supplementation were observed on

the chemical composition of the meat. However, supplementation at 6 g kg<sup>-1</sup> BW resulted in lower levels of C15:0 and C14:1 and increased proportions of n-6 fatty acids, leading to a higher n-6:n-3 ratio (Table 6).

**Table 6**  
**Fatty acid composition (g 100<sup>-1</sup> g) of meat (*Longissimus dorsi*) from steers supplemented and finished on tropical pasture (*Urochloa brizantha* cv. Marandu) during the dry season of the year**

	Supplementation level		SDM <sup>2</sup>	P-value <sup>3</sup>
	3 g kg <sup>-1</sup> of BW <sup>1</sup>	6 g kg <sup>-1</sup> of BW <sup>1</sup>		
C14:0	2.53	1.89	0.892	0.148
C15:0	0.54	0.36	0.152	0.016
C16:0	26.80	24.35	3.687	0.179
C17:0	1.45	1.27	0.228	0.106
C18:0	18.80	22.44	6.392	0.251
C20:0	0.20	0.21	0.082	0.771
C22:0	0.02	0.05	0.028	0.134
C14:1	0.32	0.20	0.103	0.018
C15:1	0.36	0.33	0.098	0.542
C16:1	3.34	3.02	0.702	0.355
C17:1	0.70	0.63	0.293	0.611
C18:1n-9t	2.52	2.24	0.709	0.420
C18:1n-9c	37.74	37.90	2.363	0.883
C18:1n-7c	1.17	1.15	0.154	0.873
C20:1	0.26	0.19	0.131	0.230
C22:1n-9	0.05	0.12	0.047	0.141
C18:2n-6c	1.44	1.82	0.529	0.147
C18:3n-6	0.63	0.12	0.113	0.185
C18:3n-3	0.40	0.25	0.171	0.081
CLA <sup>4</sup> c9t11	0.64	0.56	0.254	0.506
CLAt10c1	0.55	0.57	0.309	0.892
C20:3n-6c	0.67	0.68	0.446	0.950
C20:3n-3	0.12	0.11	0.071	0.752
C20:4n-6	0.05	0.04	0.032	0.634
C22:2n-6	0.14	0.35	0.088	0.217
C20:5n-3	0.60	0.97	0.762	0.328
DHA <sup>5</sup>	0.17	0.16	0.154	0.873
n-3	0.74	0.61	0.215	0.209
n-6	1.75	2.40	0.572	0.031
ΣSFA <sup>6</sup>	50.353	50.584	3.295	0.883
ΣMUFA <sup>7</sup>	46.453	45.782	3.172	0.661
ΣPUFA <sup>8</sup>	3.193	3.633	0.877	0.310
n-6/n-3	2.452	4.125	0.960	0.002
PUFA/SFA ratio	0.643	0.720	0.195	0.421

<sup>1</sup> Body weight; <sup>2</sup> Standard deviation of the mean; <sup>3</sup> Significant at the 0.05 probability level; <sup>4</sup> Conjugated linoleic acid; <sup>5</sup> Docosahecanoic acid; <sup>6</sup> Saturated fatty acids; <sup>7</sup> Monounsaturated fatty acids; <sup>8</sup> Polyunsaturated fatty acids

The sums of saturated, monounsaturated, and polyunsaturated fatty acids were not influenced ( $P>0.05$ ) by the increase in supplementation level during the finishing of steers on tropical pasture.

## Discussion

The forage allowance of 10.77 kg DM 100 kg BW day<sup>-1</sup>, combined with the high availability (2,093 kg ha<sup>-1</sup>) of green dry matter in the pasture (Mota et al., 2024), allowed steers to selectively consume the most nutritious portions, resulting in similar forage DM and total DM intake (Charmley et al., 2023). Delevatti et al. (2019) also observed that increasing the supplementation level (3 g kg<sup>-1</sup> to 6 g kg<sup>-1</sup> BW) did not alter forage DM or total DM intake. Low to moderate levels of supplementation, such as those tested here, typically do not induce substitution effects (Tambara et al., 2021), which could be detrimental by reducing pasture intake in favor of supplementation.

Steers receiving 6 g kg<sup>-1</sup> BW of supplement consumed greater amounts of CP and NFC, likely due to the higher concentrations of these fractions in the supplement. However, despite the increased CP and NFC intake, no effects were observed on the digestibility of NDFap or OM in the diet. It is well documented in the literature (Almeida et al., 2022; Palma et al., 2023; Silva et al., 2024) that higher intake of rumen-degradable protein is associated with enhanced ruminal OM degradation and alterations in ruminal kinetics, but this effect was not observed in our study. This suggests that the CP content of the pasture, combined with low to moderate supplementation levels, was insufficient to induce significant

changes in fermentation dynamics in the rumen of steers (Franco et al., 2021). Similarly, Rocha et al. (2019) and Cediel-Devia et al. (2024) reported that increased CP intake did not affect NDFap digestibility in the diets of steers finished on tropical pasture.

Despite spending more time at the trough, the daily pattern of chewing activities (grazing and rumination) and idleness in steers did not vary between supplementation levels, possibly due to the similar forage intake observed among animals (Smith et al., 2021), regardless of treatment. Yu et al. (2024) also emphasize that animals subjected to the same grazing pressure exhibit similar feeding behavior. In this context, the observed biting rate, mass, number, and duration in steers, irrespective of supplementation level, indicate that the pasture had a uniform structure and that supplementation did not influence the animals' eagerness for pasture consumption (Silva et al., 2020). On the other hand, chewing time and the number of chews per cud were lower in steers supplemented at 6 g kg<sup>-1</sup> BW, likely because the concentrate ingredients in the supplement had a lower volume. The higher concentrate intake in steers supplemented at 6 g kg<sup>-1</sup> BW reduced the volume of ruminal content aspirated by the esophagus during rumination, resulting in cuds with less forage and more concentrate compared to those from steers receiving 3 g kg<sup>-1</sup> BW. This likely led to shorter chewing times and fewer chews per cud, as the lower fiber content of the concentrate reduced its physical resistance to breakdown compared to forage (Schadt et al., 2012; Nasrollahi et al., 2015). Lins et al. (2022) also reported a reduction in cud chewing time and the number of chews in supplemented steers on tropical pasture.

Body weight at slaughter, hot carcass weight, and hot carcass yield were not influenced by supplementation level, possibly due to the similar energy intake among steers (McPhee et al., 2006). In contrast, total weight gain (TWG) and average daily gain (ADG) were 29% higher in animals supplemented with 6 g kg<sup>-1</sup> BW compared to those receiving 3 g kg<sup>-1</sup> BW. We suggest that the observed differences in TWG and ADG, despite the lack of variation in body weight at slaughter and hot carcass yield, may be related to the cattle's weight gain curve. Weight gain tended to be accelerated early in the supplementation period, particularly at 6 g kg<sup>-1</sup> BW, before slowing as fat deposition increased toward the end of the finishing phase (Owens & Gardner, 2000; Sampaio et al., 2017). The initially pronounced weight gain in steers supplemented with 6 g kg<sup>-1</sup> BW, driven by higher CP and NFC intake, may have resulted in earlier fattening, leading to a premature reduction in gain rate (Zinn et al., 2008). This may have allowed steers receiving 3 g kg<sup>-1</sup> BW of supplement to reach similar body and hot carcass weights after 135 days of finishing, despite significantly lower TWG and ADG (Severo et al., 2023). Similarly, Almeida et al. (2018) reported no effect of supplementation level (3 g kg<sup>-1</sup> to 9 g kg<sup>-1</sup> BW) on body weight at slaughter and carcass weight.

Carcass yields in steers were not influenced by supplementation level, likely due to the similarity in carcass weights and body weight at slaughter (Coyne et al., 2019). Vitor et al. (2022) also found no effect of supplementation levels (1.5 g kg<sup>-1</sup> or 4.0 g kg<sup>-1</sup> BW) on the carcass yields of zebu steers finished on tropical pasture. The similarity in DMI, despite differences in ADG, resulted in

the same feed efficiency for steers finished with either 3 or 6 g kg<sup>-1</sup> BW of concentrate supplement (Beck et al., 2024). Similarly, Barroso et al. (2025) reported that increasing supplementation from 2 g kg<sup>-1</sup> to 5 g kg<sup>-1</sup> BW did not affect the feed efficiency of steers finished on tropical pasture.

Carcass fat is essential for preserving meat quality during post-slaughter chilling (Boito et al., 2017). In pasture-fed finishing systems, carcass fat levels are typically low (less than 4 mm) but are highly dependent on genotype (Schumacher et al., 2022; Pacheco et al., 2023) and the genetic merit of the animals (Araújo et al., 2022). In this study, supplementation level did not affect carcass fatness, likely due to the similar energy intake at both supplementation levels (Moura et al., 2023). In this context, crude fat content in the meat which is linked to intramuscular fat was also unaffected by supplementation level, which can be explained by the similarity in energy intake among steers (Park et al., 2018). Sampaio et al. (2017) likewise found no effect of supplementation level on subcutaneous or total carcass fat in steers finished on tropical pasture.

Increasing the supplementation level from 3 g kg<sup>-1</sup> to 6 g kg<sup>-1</sup> BW induced subtle changes in the fatty acid composition of the meat. Steers finished with 3 g kg<sup>-1</sup> BW of concentrate supplement produced meat with higher levels of C15:0 and C14:1 fatty acids compared to those finished with 6 g kg<sup>-1</sup> BW. This likely occurred because medium-chain fatty acids (C12 to C16) originate from *de novo* synthesis, a process that relies on ruminal precursors (acetate and  $\beta$ -OH-butyrate), which are proportionally more abundant in diets with higher NDF content (Dalrymple et al., 2014; Berton et al., 2016).

The higher content of  $\omega$ -6 fatty acids, as well as the higher  $\omega$ -6: $\omega$ -3 ratio, in the meat of steers supplemented with 6 g kg<sup>-1</sup> BW can be attributed to the increased consumption of corn grain present in the concentrate. Corn contains approximately 4% lipids, primarily composed of C18:2  $\omega$ -6 fatty acids, which, after absorption in the small intestine, can be incorporated into adipocytes (Urrutia et al., 2020). Taffarel et al. (2020) also observed an increase in  $\omega$ -6 fatty acid content with higher levels of corn supplementation in steers.

## Conclusion

Increasing the level of concentrate supplementation from 3 g kg<sup>-1</sup> to 6 g kg<sup>-1</sup> BW in steers enhances protein and non-fiber carbohydrate intake, improves average daily gain, and increases the  $\omega$ -6 fatty acid content in meat. However, over a 135-day finishing period on pasture, a higher supplementation level does not appear to affect feed efficiency, body weight at slaughter, carcass weight, carcass fatness, or the content of most fatty acids in the meat. Therefore, we recommend a supplementation level of 3 g kg<sup>-1</sup> BW of concentrate for steers finished on tropical pasture.

## References

- Almeida, D. M. de, Silva, A. L. da, Paulino, M. F., Silva, T. E. da, Detmann, E., & Marcondes, M. I. (2022). Performance of *Bos indicus* beef cattle supplemented with mineral or with concentrates in tropical *Urochloa decumbens* pastures: a meta-regression approach. *Animal Feed Science and Technology*, 283(1), 115178. doi: 10.1016/j.anifeedsci.2021.115178
- Almeida, V. V. S. de, Oliveira, A. C., Oliveira, H. C., Silva, R. R., & Lima, D. M. de, Jr. (2018). Body weight components of Nelore steers finished in tropical pastures. *Acta Scientiarum. Animal Sciences*, 41(1), 39005. doi: 10.4025/actascianimsci.v41i1.39005
- Araújo, T. L. A. C. de, Feijó, G. L. D., Neves, A. P., Nogueira, É., Oliveira, L. O. F. de, Gomes, M. D. N. B., Egito, A. A. do, Ferraz, A. L. J., Menezes, G. R. D. O., Latta, K. I., Ferreira, J. R., Vieira, D. G., Pereira, E. S., & Gomes, R. D. C. (2022). Effect of genetic merit for backfat thickness and paternal breed on performance, carcass traits, and gene expression in subcutaneous adipose tissue of feedlot-finished steers. *Livestock Science*, 263(3), 104998. doi: 10.1016/j.livsci.2022.104998
- Association of Official Analytical Chemists (2019). *Official methods of analysis* (21nd ed., vol. 3). AOAC.
- Baggio, C., Carvalho, P. C. de F., Silva, J. L. S. da, Anghinoni, I., Lopes, M. L. T., & Thurow, J. M. (2009). Padrões de deslocamento e captura de forragem por novilhos em pastagem de azevém-anual e aveia-preta manejada sob diferentes alturas em sistema de integração lavoura-pecuária. *Revista Brasileira de Zootecnia*, 38(2), 215-222. doi: 10.1590/S1516-35982009000200001
- Barbero, R. P., Ribeiro, A. C. de C., Moura, A. M., Longhini, V. Z., Mattos, T. F. de A., & Barbero, M. M. D. (2021). Production potential of beef cattle in tropical pastures: a review. *Ciência Animal Brasileira*, 22(2), e69609. doi: 10.1590/1809-6891v22e-69609

- Barroso, D. S., Silva, F. F. da, Azevêdo, J. A. G., Carvalho, G. G. P. de, Trindade, G., Jr., Silva, J. W. D., Paixão, T. R., Mendes, F. B. L., Lima, D. M. de, Jr., & Silva, R. R. (2025). Performance, carcass traits, and meat attributes of steers finished on tropical pasture under increasing supplementation levels. *Chilean Journal of Agricultural Research*, 85(2), 161-169. doi: 10.4067/s0718-58392025000200161
- Barroso, D. S., Silva, F. F. da, Carvalho, G. G. P. de, Santos, L. V., Trindade, G., Jr., Silva, J. W. D., Paixão, T. R., Mendes, F. B. L., Lima, D. M. de, Jr., & Silva, R. R. (2024). Increasing levels of concentrate supplement in the post-weaning period of steers on tropical pasture during the rainy season. *Chilean Journal of Agricultural Research*, 84(4), 467-475. doi: 10.4067/S0718-58392024000400467
- Beck, M. R., Gouvêa, V. N., Smith, J. K., Proctor, J. A., Beck, P. A., & Foote, A. P. (2024). Relationships between individual animal variation in dry matter intake and animal performance and feed efficiency of finishing beef cattle. *Applied Animal Science*, 40(5), 639-646. doi: 10.15232/aas.2024-02583
- Berton, M. P., Fonseca, L. F. S., Gimenez, D. F. J., Utembergue, B. L., Cesar, A. S. M., Coutinho, L. L., Lemos, M. V. A. de, Aboujaoude, C., Pereira, A. S. C., Silva, R. M. de O., Stafuzza, N. B., Feitosa, F. L. B., Chiaia, H. L. J., Olivieri, B. F., Peripolli, E., Tonussi, R. L., Gordo, D. M., Espigolan, R., Ferrinho, A. M., ... Baldi, F. (2016). Gene expression profile of intramuscular muscle in Nellore cattle with extreme values of fatty acid. *BMC Genomics*, 17(1), 972. doi: 10.1186/s12864-016-3232-y
- Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, 37(8), 911-917. doi: 10.1139/o59-099
- Boito, B., Kuss, F., Menezes, L. F. G. de, Lisbinski, E., Paris, M. de, & Cullmann, J. R. (2017). Influence of subcutaneous fat thickness on the carcass characteristics and meat quality of beef cattle. *Ciência Rural*, 48(1), e20170333. doi: 10.1590/0103-8478cr20170333
- Bürger, P. J., Pereira, J. C., Queiroz, A. C. de, Coelho da Silva, J. F., Valadares, S. de C., Fº., Cecon, P. R., & Casali, A. D. P. (2000). Comportamento ingestivo em bezerros holandeses alimentados com dietas contendo diferentes níveis de concentrado. *Revista Brasileira de Zootecnia*, 29(1), 236-242. doi: 10.1590/S1516-35982000000100031
- Campbell, A. G. (1966). Grazed pasture parameters. I. Pasture dry-matter production and availability in a stocking rate and grazing management experiment with dairy cows. *The Journal of Agricultural Science*, 67(2), 199-210. doi: 10.1017/S0021859600068283
- Cardoso, G. dos S., Machado, D. S., Schumacher, L. L., Fernandes, C. de A., Antunes, D. P., Schenkel, M. dos S., Rodrigues, A. Z., & Brondani, I. L. (2020). A meta-analysis of the effects of dietary supplementation in tropical forage-fed cattle. *Semina: Ciências Agrárias*, 41(5supl. 1), 2381-2390. doi: 10.5433/1679-0359.2020v41n5supl1p2381

- Carrillo, J. A., Bai, Y., He, Y., Li, Y., Cai, W., Bickhart, D. M., Liu, G., Barao, S. M., Sonstegard, T., & Song, J. (2021). Growth curve, blood parameters and carcass traits of grass-fed Angus steers. *Animal*, 15(11), 100381. doi: 10.1016/j.animal.2021.100381
- Casali, A. O., Detmann, E., Valadares, S., F<sup>o</sup>., Pereira, J. C., Henriques, L. T., Freitas, S. G. de, & Paulino, M. F. (2008). Influência do tempo de incubação e do tamanho de partículas sobre os teores de compostos indigestíveis em alimentos e fezes bovinas obtidos por procedimentos in situ. *Revista Brasileira de Zootecnia*, 37(2), 335-342. doi: 10.1590/S1516-35982008000200021
- Cediel-Devia, D. C., Schaitz, L. H., Silva, F. F. da, Santos, L. V., Silva, A. P. G. da, Santos, M. da C., Dueñez, W. Y. S., Melgar, O. R. A., Paixão, T. R., Silva, J. W. D., Araújo, T. L. A. C. de, Lima, D. M. de, Jr., & Silva, R. R. (2024). Performance, carcass traits, and meat fatty acid profile of post-weaning and finishing zebu steers on tropical pasture with three low-intake supplementation strategies. *Animals*, 14(17), 2486. doi: 10.3390/ani14172486
- Charmley, E., Thomas, D., & Bishop-Hurley, G. J. (2023). Revisiting tropical pasture intake: what has changed in 50 years? *Animal Production Science*, 63(18), 1851-1865. doi: 10.1071/AN23045
- Coyne, J. M., Evans, R. D., & Berry, D. P. (2019). Dressing percentage and the differential between live weight and carcass weight in cattle are influenced by both genetic and non-genetic factors. *Journal of Animal Science*, 97(4), 1501-1512. doi: 10.1093/jas/skz056
- Dalrymple, B. P., Guo, B., Zhou, G. H., & Zhang, W. (2014). Using muscle gene expression to estimate triacylglyceride deposition, and relative contributions of fatty acid synthesis and fatty acid import in intramuscular fat in cattle. *Animal Production Science*, 54(9), 1436. doi: 10.1071/AN14247
- Delevatti, L. M., Romanzini, E. P., Koscheck, J. F. W., Ross de Araujo, T. L. da, Renesto, D. M., Ferrari, A. C., Barbero, R. P., Mulliniks, J. T., & Reis, R. A. (2019). Forage management intensification and supplementation strategy: intake and metabolic parameters on beef cattle production. *Animal Feed Science and Technology*, 247(1), 74-82. doi: 10.1016/j.anifeedsci.2018.11.004
- Detmann, E., Paulino, M. F., Campos Valadares, S. de, F<sup>o</sup>., & Huhtanen, P. (2014). Nutritional aspects applied to grazing cattle in the tropics: a review based on Brazilian results. *Semina Ciências Agrárias*, 35(4), 2829-2854. doi: 10.5433/1679-0359.2014v35n4Suplp2829
- Detmann, E., Silva, T. E., Valadares, S. de C., F<sup>o</sup>., Sampaio, C. B., & Palma, M. N. N. (2016). Prediction of the energy value of cattle diets based on the chemical composition of feeds. In S. de C. Valadares F<sup>o</sup>., L. F. Costa e Silva, M. P. Gionbelli, P. P. Rotta, M. I. Marcondes, M. L. Chizzotti, & L. F. Prados (Eds.), *Nutrient requirements of zebu and crossbred cattle* (3rd ed., pp. 89-126). Viçosa: UFV.
- Detmann, E., Souza, M. A. de, Valadares, S. de C., F<sup>o</sup>., Queiroz, A. C. de, Berchielli, T. T., Saliba, E. de O. S., Cabral, L. da S., Pina, D. dos S., Ladeira, M. M., & Azevedo, J. A. G. (2012). *Métodos para análise de*

- alimentos*. Visconde Do Rio Branco: Suprema.
- Folch, J., Lees, M., & Stanley, G. (1957). A simple method for the isolation and purification of total lipides from animal tissues. *Journal of Biological Chemistry*, 226(1), 497-509. doi: [https://doi.org/10.1016/S0021-9258\(18\)64849-5](https://doi.org/10.1016/S0021-9258(18)64849-5)
- Franco, M. O., Detmann, E., Batista, E. D., Rufino, L. M. A., Paulino, M. F., & Valadares, S. C., Fº. (2021). Nutritional performance and metabolic characteristics of cattle fed tropical forages with protein and starch supplementation. *Anais da Academia Brasileira de Ciências*, 93(3), 1-18. doi: 10.1590/0001-3765202120190487
- Gardner, A. L. (1986). *Técnicas de pesquisa em pastagens e aplicabilidade de resultados em sistemas de produção* (Issue 634). IICA Biblioteca Venezuela.
- Greenwood, P. L. (2021). Review: an overview of beef production from pasture and feedlot globally, as demand for beef and the need for sustainable practices increase. *Animal*, 15(Suppl 1), 100295. doi: 10.1016/j.animal.2021.100295
- Haydock, K. P., & Shaw, N. H. (1975). The comparative yield method for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry*, 15(76), 663-670. doi: 10.1071/EA9750663
- International Organization for Standardization [ISO] (1978). ISO 5509:1978: *Animal and vegetable fats and oils — Preparation of methyl esters of fatty acids*. (1st ed). Geneva: ISO.
- Johnson, A. D. (1978). Sample preparation and chemical analysis of vegetation. In L. t' Manetje (Ed.), *Measurement of grassland vegetation and animal production* (vol. 1, nº. 52, pp. 96-102). Wallingford: Commonwealth Agricultural Bureaux.
- Lins, T. O. J. D'A., Silva, R. R., Mendes, F. B. L., Silva, F. F. da, Bastos, E. S., Paixão, T. R., Silva, J. W. D., Conceição Santos, M. da, Figueiredo, G. C., Alba, H. D. R., & Carvalho, G. G. P. de. (2022). Feeding behavior of post-weaned crossbred steers supplemented in the dry season of the year. *Tropical Animal Health and Production*, 54(4), 203-214. doi: 10.1007/s11250-022-03209-4
- McPhee, M. J., Oltjen, J. W., Famula, T. R., & Sainz, R. D. (2006). Meta-analysis of factors affecting carcass characteristics of feedlot steers. *Journal of Animal Science*, 84(11), 3143-3154. doi: 10.2527/jas.2006-175
- Mota, L. M. de S., Cezar, B. H. M., Teixeira, O. de S., Pazdiora, R. D., Fernandes, A. M., Matos, G. B. da C., Salman, A. K. D., Machado, D. S., Pacheco, R. F., & Angelo, I. D. V. (2024). Grazing management of Panicum maximum cvv. Mombaça and Tanzania pastures for beef cattle: a meta-analytic study. *Crop & Pasture Science*, 75(9), CP24001. doi: 10.1071/CP24001
- Moura, J. R. de F., Ítavo, L. C. V., Gurgel, A. L. C., Ítavo, C. C. B. F., Nadai Bonin Gomes, M. de, Longhini, V. Z., Dias, A. M., Santos Difante, G. dos, Santos, G. T. dos, Arcanjo, Â. H. M., & Chay-Canul, A. J. (2023). Prediction models of carcass characteristics from

- non castrated Nelore cattle finished in the feedlot system under tropical conditions. *Tropical Animal Health and Production*, 55(6), 427. doi: 10.1007/s11250-023-03854-3
- Nasrollahi, S. M., Imani, M., & Zebeli, Q. (2015). A meta-analysis and meta-regression of the effect of forage particle size, level, source, and preservation method on feed intake, nutrient digestibility, and performance in dairy cows. *Journal of Dairy Science*, 98(12), 8926-8939. doi: 10.3168/jds.2015-9681
- National Research Council (2016). *Nutrient requirements of beef cattle* (8nd rev. ed.). National Academies Press, NRC.
- Nogoy, K. M. C., Sun, B., Shin, S., Lee, Y., Zi Li, X., Choi, S. H., & Park, S. (2022). Fatty acid composition of grain- and grass-fed beef and their nutritional value and health implication. *Food Science of Animal Resources*, 42(1), 18-33. doi: 10.5851/kosfa.2021.e73
- Owens, F. N., & Gardner, B. A. (2000). A review of the impact of feedlot management and nutrition on carcass measurements of feedlot cattle. *Journal of Animal Science*, 77(E-Suppl.), 1-18. doi: 10.2527/jas2000.00218812007700ES0034x
- Pacheco, R. F., Machado, D. S., Restle, J., Sartori, D. B. S., Costa, P. T., & Vaz, R. Z. (2023). Meta-analysis of meat quality of cattle slaughtered with different subcutaneous fat thicknesses. *Pesquisa Agropecuária Brasileira*, 58(4), e03110. doi: 10.1590/s1678-3921.pab2023.v58.03110
- Palma, M. N. N., Reis, W. L. S., Rodrigues, J. P. P., Silva, T. E., Franco, M. O., Rennó, L. N., & Detmann, E. (2023). Strategies of energy supplementation for cattle fed tropical forage and infrequently supplemented with protein. *Animal Feed Science and Technology*, 297(3), 115599. doi: 10.1016/j.anifeeds.2023.115599
- Park, S. J., Beak, S., Jung, D. J. S., Kim, S. Y., Jeong, I. H., Piao, M. Y., Kang, H. J., Fassah, D. M., Na, S. W., Yoo, S. P., & Baik, M. (2018). Genetic, management, and nutritional factors affecting intramuscular fat deposition in beef cattle — a review. *Asian-Australasian Journal of Animal Sciences*, 31(7), 1043-1061. doi: 10.5713/ajas.18.0310
- Regulamento da Inspeção Industrial e Sanitária de Produtos de Origem Animal (2017). *Regulamento da inspeção industrial e sanitária de produtos de origem animal*. RIISPOA.
- Rocha, W. J. B., Silva, R. R., Silva, F. F. da, Carvalho, G. G. P. de, Silva, A. P. G. da, Silva, J. W. D., Paixão, T. R., Freitas, T. B., Mendes, F. B. L., Barroso, D. S., Souza, S. O. de, & Santos, L. V. (2019). Intake, digestibility, and growth performance of Girolando bulls supplemented on pasture in Bahia, Brazil. *Tropical Animal Health and Production*, 51(6), 1413-1420. doi: 10.1007/s11250-019-01824-2
- Rodrigo, A. (2024). Beef production and the beef evaluation system in Chile: description, characterization, and quality. *Animal Frontiers*, 14(2), 21-28. doi: 10.1093/af/vfae003

- Saliba, E. de O. S., & Rodriguez, N. M. (2009). Uso de indicadores na avaliação da digestibilidade em ruminantes. In L. F. P. Silva, & F. P. Rennó (Eds.), *Avanços em técnicas de pesquisa em nutrição de ruminantes* (vol. 1, pp. 50-67). São Paulo: USP.
- Sampaio, R. L., Resende, F. D. de, Reis, R. A., Oliveira, I. M. de, Custódio, L., Fernandes, R. M., Pazdiora, R. D., & Siqueira, G. R. (2017). The nutritional interrelationship between the growing and finishing phases in crossbred cattle raised in a tropical system. *Tropical Animal Health and Production*, *49*(5), 1015-1024. doi: 10.1007/s11250-017-1294-8
- Schadt, I., Ferguson, J. D., Azzaro, G., Petriglieri, R., Caccamo, M., Van Soest, P., & Licitra, G. (2012). How do dairy cows chew? Particle size analysis of selected feeds with different particle length distributions and of respective ingested bolus particles. *Journal of Dairy Science*, *95*(8), 4707-4720. doi: 10.3168/jds.2011-5118
- Schumacher, M., DelCurto-Wyffels, H., Thomson, J., & Boles, J. (2022). Fat deposition and fat effects on meat quality a review. *Animals*, *12*(12), 1550. doi: 10.3390/ani12121550
- Severo, M. M., Menezes, L. F. G. de, Kuss, F., Paris, W., Haveroth, R. C., Souto, G. B., & Sanches, A. C. (2023). Effect of the gain rate during growing phase on the performance and characteristics of carcass and meat of super precocious steers. *Animal Science Journal*, *94*(1), e13803. doi: 10.1111/asj.13803
- Silva, F. F. da, Sá, J. F. de, Schio, A. R., Ítavo, L. C. V., Silva, R. R., & Mateus, R. G. (2009). Suplementação a pasto: disponibilidade e qualidade x níveis de suplementação x desempenho. *Revista Brasileira de Zootecnia*, *38*(Suppl. 1), 371-389. doi: 10.1590/S1516-35982009001300037
- Silva, R. R., Silva, F. F., Prado, I. N., Carvalho, G. G. P., Franco, I. L., Almeida, V. S., Cardoso, C. P., & Ribeiro, M. H. S. (2006). Comportamento ingestivo de bovinos. Aspectos metodológicos. *Archivos de Zootecnia*, *55*(211), 293-296.
- Silva, T. E. da, Oliveira, C. V. R. de, Rodrigues, A. N., Palma, M. N. N., Camacho, L. F., Rennó, L. N., Franco, M. O., & Detmann, E. (2024). Effects of supplementation frequency on nutritional performance and metabolism of cattle fed low-quality tropical forage. *Animal Feed Science and Technology*, *318*(12), 116117. doi: 10.1016/j.anifeeds.2024.116117
- Silva, V. S. da, Brindani, I. L., Alves, D. C., Fº., Colvero, P. C. de P., Moura, A. F. de, Doingues, C. C., Silva, M. B. da, & Silva, M. A. da. (2020). Ingestive behavior and movement patterns of steers grazing sorghum and supplemented with concentrate. *Semina Ciências Agrárias*, *41*(6supl2), 3365-3376. doi: 10.5433/1679-0359.2020v41n6 Supl2p3365
- Simioni, T. A., Torrecilhas, J. A., Messana, J. D., Granja-Salcedo, Y. T., Vito, E. S., Lima, A. R. C., Sanchez, J. M. D., Reis, R. A., & Berchielli, T. T. (2021). Influence of growing-phase supplementation strategies on intake and performance of different beef cattle genotypes in finishing phase on pasture or feedlot. *Livestock Science*, *251*(9), 104653. doi: 10.1016/j.livsci.2021.104653

- Smith, W. B., Galyean, M. L., Kallenbach, R. L., Greenwood, P. L., & Scholljegerdes, E. J. (2021). Understanding intake on pastures: how, why, and a way forward. *Journal of Animal Science*, 99(6), skab062. doi: 10.1093/jas/skab062
- Taffarel, T. C., Menezes, L. F. G. de, Kuss, F., Paris, W., Nörnberg, J. L., Farenzena, R., Lazzarotto, E. F. C. D. O., & Hirai, M. M. G. (2020). Intramuscular fatty acid composition of steers finished on oat pastures mixture with vetch or cornmeal supplementation. *Ciência Rural*, 50(6), e20200030. doi: 10.1590/0103-8478cr20200030
- Tambara, A. A. C., Härter, C. J., Rabelo, C. H. S., & Kozloski, G. V. (2021). Effects of supplementation on production of beef cattle grazing tropical pastures in Brazil during the wet and dry seasons: a meta-analysis. *Revista Brasileira de Zootecnia*, 50(2), 1-22. doi: 10.37496/rbz5020210020
- Titgemeyer, E. C., Armendariz, C. K., Bindel, D. J., Greenwood, R. H., & Löest, C. A. (2001). Evaluation of titanium dioxide as a digestibility marker for cattle. *Journal of Animal Science*, 79(4), 1059. doi: 10.2527/2001.7941059x
- Torrecilhas, J. A., Vito, E. S., Fiorentini, G., Castagnino, P. de S., Simioni, T. A., Lage, J. F., Baldi, F., Duarte, J. M., Silva, L. G. da, Reis, R. A., & Berchielli, T. T. (2021). Effects of supplementation strategies during the growing phase on meat quality of beef cattle finished in different systems. *Livestock Science*, 247(5), 104465. doi: 10.1016/j.livsci.2021.104465
- Tsakiridis, A., Hanrahan, K., Breen, J., O'Donoghue, C., & Wallace, M. (2024). Modelling pasture-based beef production costs using panel data from farms with different soil quality. *Review of Agricultural, Food and Environmental Studies*, 106(1), 1-71. doi: 10.1007/s41130-023-00203-8
- Universidade Federal de Viçosa [UFV] (2001). *SAEG - Sistema de Análises Estatísticas e Genéticas*. (Versão 8.0). Viçosa: UFV, 142.
- Urrutia, O., Mendizabal, J. A., Alfonso, L., Soret, B., Insausti, K., & Arana, A. (2020). Adipose tissue modification through feeding strategies and their implication on adipogenesis and adipose tissue metabolism in ruminants. *International Journal of Molecular Sciences*, 21(9), 3184. doi: 10.3390/ijms21093183
- Vitor, A. da C. P., Pedreira, M. dos S., Silva, A. S., Pezenti, E., Silva, L. C. da, Silva, H. A. da, Diavão, J., & Morenz, M. J. F. (2022). Feeding strategy during growing phase on the performance and carcass traits in beef bulls finished on the pasture. *Tropical Animal Health and Production*, 54(5), 302. doi: 10.1007/s11250-022-03270-z
- Weiss, W. P. (1999). Energy prediction equations for ruminant feeds. *Proceedings of the Cornell Nutrition Conference Feed Manufacturers*, New York, USA, 61.
- Wilm, H. G., Castello, D. F., & Klipple, G. E. (1944). Estimating forage yield by the double-sampling method. *Journal of the American Society of Agronomy*, 36(1), 194-203. doi: 10.2134/agronj1944.00021962003600030003x

- Yu, T., Yan, R., Zhang, C., Chen, S., Zhang, Z., Guo, L., Hu, T., Jiang, C., Wang, M., Bai, K., Zhou, W., & Wu, L. (2024). How does grazing pressure affect feed intake and behavior of livestock in a meadow steppe in northern China and their coupling relationship. *Science of The Total Environment*, 908(6), 168472. doi: 10.1016/j.scitotenv.2023.168472
- Zinn, R. A., Barreras, A., Owens, F. N., & Plascencia, A. (2008). Performance by feedlot steers and heifers: daily gain, mature body weight, dry matter intake, and dietary energetics. *Journal of Animal Science*, 86(10), 2680-2689. doi: 10.2527/jas.2007-0561