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RESEARCH ARTICLE

Increasing levels of concentrate supplementation for heifers (Nellore × Angus) finished on tropical pasture

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ABSTRACT

Concentrate supplementation during the finishing phase in tropical pastures improves the average daily gain and carcass characteristics of the animals. The objective of this study was to evaluate the effects of increasing levels of concentrate supplementation on nutrient intake and digestibility, ruminal fermentation parameters, and the performance of heifers finished on *Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs 'Mombaça' pasture. Forty heifers (½ Nellore × ½ Angus), with an average body weight of 312.65 ± 17.95 kg and 16 mo age, were distributed in a completely randomized design. To analyze ruminal parameters, four rumen-fistulated heifers were used in a 4×4 Latin square design. Supplementation was provided at four levels: 0.2%, 0.3%, 0.4%, and 0.5% of body weight (BW) over 134 d. A linear increase ($P < 0.05$) was observed in the intake of total DM, organic matter, crude protein (CP), and non-fibrous carbohydrates with increasing supplementation levels. However, the digestibility of neutral detergent fiber and CP decreased linearly ($P < 0.05$) and quadratically ($P < 0.05$), respectively, with increasing supplementation. Greater supplementation levels also reduced ($P < 0.05$) the concentrations of short chain fatty acids, acetate, and propionate in the rumen. Final body weight (398 kg) and average daily gain (0.64 kg d^{-1}) were not affected ($P > 0.05$) by supplementation level, but gross feed efficiency declined ($P < 0.05$) as supplementation increased. Increasing concentrate supplementation from 0.2% to 0.5% BW in ½ Nellore × ½ Angus heifers finished on *M. maximus* 'Mombaça' pasture did not affect average daily gain but reduced feed efficiency. Therefore, lower supplementation levels (0.2% BW) are recommended.

Key words: Guinea grass, heifer finishing, heifer performance, *Megathyrsus maximus*, ruminal fermentation.

INTRODUCTION

Cattle production on pasture represents a sustainable alternative that, when well-managed, can contribute to atmospheric C sequestration (Cusack et al., 2021) and the conversion of cellulose biomass into high-biological-value protein (Tedeschi and Beauchemin, 2023). However, variations in environmental conditions due to seasonality can present significant challenges regarding the quantity and quality of forage available to animals (Pereira et al., 2022). In this context, supplementation ensures greater stability in cattle production systems on pasture by providing a more consistent nutrient supply throughout the livestock cycle (Barroso et al., 2024).

The efficiency of a supplementation strategy depends on several biotic and abiotic factors, especially pasture availability and quality (Barbero et al., 2021). Tropical grasses experience fluctuations in biomass production and quality throughout the year, with marked differences among cultivars and across the rainy, transitional, and dry seasons (Bitencourt et al., 2023; Rodrigues et al., 2023). In this scenario, supplementation strategies (specifically the amount and composition of the supplement) have produced more consistent results during the dry season and with intermediate supplementation levels (0.3% to 0.6% of body weight [BW]) (Tambara et al., 2021). Moreover, Cardoso et al. (2020) reported that both protein and energy supplements can improve weight gain and final body weight during the finishing phase. On the other hand, studies conducted during transitional periods between seasons (dry/rainy and rainy/dry) (Pasquini Neto et al., 2025) and involving other animal categories (e.g., heifers) remain scarce and show inconsistent results (Martini et al., 2023).

We hypothesized that a moderate level of supplementation would be most suitable for heifers finished on *Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs pasture during the rainy season. Therefore, this study aimed to evaluate the effects of increasing levels of concentrate supplementation on intake, digestibility, ruminal parameters, and performance of heifers finished on *M. maximus* 'Mombaça' pasture during the rainy season.

MATERIALS AND METHODS

Location, animals, and treatments

All experimental procedures complied with the Ethics Committee on Animal Use (license 141/2016, Ethics Committee on Animal Use/Universidade Estadual do Sudoeste da Bahia [UESB], Bahia, Brazil).

The experiment was conducted at the Itaju do Colônia Animal Science Experimental Station (EZICO), located in the municipality of Itaju do Colônia (15°8'29" S, 30°43'28" W), Bahia, Brazil. According to the Köppen classification, the area has an Am climate, characterized by a hot, humid environment with annual precipitation between 750 and 1250 mm.

Forty industrial crossbred heifers (½ Nellore × ½ Angus), with an average body weight of 312.65 ± 17.95 kg and 16 mo age, were used during the finishing phase. The field phase lasted 134 d, with the first 14 d allocated to adaptation to the experimental diets and management practices. At the beginning of the experiment, all animals underwent control of ecto- and endoparasites and were vaccinated according to the health authority schedule for the state of Bahia, Brazil.

The experimental design was completely randomized, with four treatments and 10 replicates per treatment. Treatments consisted of increasing levels of concentrate supplementation (0.2%, 0.3%, 0.4%, and 0.5% BW) (Table 1). Diets were formulated following NRC (2016) guidelines to meet the nutritional requirements for animals with a body weight of 350 kg, predicting gains of 0.5 kg d^{-1}. The supplement was provided daily at 10:00 h.

Table 1. Chemical and centesimal composition of experimental supplements and chemical composition of forage obtained through simulated grazing. BW: Body weight; NDFap: neutral detergent fiber corrected for ash and protein; ADF: acid detergent fiber; iNDF: indigestible neutral detergent fiber; NFC: non-fibrous carbohydrates; TDN: total digestible nutrients. [1]Guaranteed levels: Ca (maximum) 185 g kg^{-1}; Ca (minimum) 160 g kg^{-1}; P (minimum) 80 g kg^{-1}; Na (minimum) 107 g kg^{-1}; S (minimum) 12 g kg^{-1}; Mg (minimum) 5000 mg kg^{-1}; Co (minimum) 107 mg kg^{-1}; Cu (minimum) 1300 mg kg^{-1}; I (minimum) 70 mg kg^{-1}; Mn (minimum) 1000 mg kg^{-1}; Se (minimum) 18 mg kg^{-1}; Zn (minimum) 4000 mg kg^{-1}; F (maximum) 800 mg kg^{-1}. NDFap: Neutral detergent fiber corrected for ash and protein; ADF: acid detergent fiber; iNDF: indigestible neutral detergent fiber; NFC: non-fibrous carbohydrates; TDN: total digestible nutrients.

		Supplementation level (% BW)			
		0.2	0.3	0.4	0.5
Corn, %		49.22	68.86	80.06	86.33
Soybean meal, %		31.34	19.08	11.30	6.77
Urea, %		13.91	8.39	5.91	4.50
Mineral salt[1], %		5.53	3.67	2.73	2.4
	Megathyrsus maximus				
Dry matter, g kg^{-1} as fed	304.5	850.6	850.3	837.7	844.5
Mineral matter, g kg^{-1} DM	104.2	79.8	51.8	44.8	34.6
Crude protein, g kg^{-1} DM	102.3	570.6	466.3	456.8	307.0
Ether extract, g kg^{-1} DM	23.2	28.3	43.2	25.5	56.7
NDFap, g kg^{-1} DM	673.2	122.9	123.0	115.1	112.6
ADF, g kg^{-1} DM	347.1	29.6	26.7	26.5	29.0
iNDF, g kg^{-1} DM	321.1	25.9	24.8	26.0	27.2
NFC, g kg^{-1} DM	110.3	634.4	558.6	517.0	570.3
TDN, g kg^{-1} DM	444.6	797.2	781.3	693.6	629.0

Animal management on pasture

The animals were distributed across a 21 ha experimental area composed of 16 paddocks of approximately 1.31 ha each, planted with *Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs 'Mombaça'. These were organized into four modules of four paddocks, each equipped with troughs accessible from both sides and with drinkers.

Each treatment group remained for 28 d in one set of four paddocks. Every 7 d, the animals were rotated among the paddocks within the same set to control for potential paddock-related effects (e.g., pasture availability, water/trough location, topography, shading, etc.) After 28 d, each group was moved to a new set of four paddocks, continuing this rotation until all paddocks had been used.

Forage assessment

The pasture assessment was carried out at 28 d intervals, both in the entry paddocks (new set of four paddocks) and in the exit paddocks (those where the animals had remained for a 28 d period).

The comparative yield method was adopted to assess forage availability. This method combines a direct (cutting) and an indirect (visual) approach. To conduct the visual assessment, on the first day of each period and in each paddock, a metal square (1.0 m^2) was randomly thrown 50 times, and the mass of forage inside the quadrat was visually estimated using scores. For the direct assessment, two samples for each score observed per paddock were collected using gardening shears. The weight of the forage inside each 1.0 m^2 quadrat was measured using a digital scale accurate to three decimal places. After weighing, the forage samples were separated into morphological components (leaf, stem + sheath, and senescent and dead material), which were weighed individually to determine the availability of each component and to calculate the leaf:stem ratio.

To represent the forage consumed by the animals, samples for chemical composition analysis were obtained through simulated grazing. This method involves observing the animals during grazing (height of the grazed layer and morphological components prehended) and collecting similar plant material.

The forage samples were pre-dried in a forced-air oven (55 °C) until constant weight was reached, then ground to 1 mm using a knife mill. After determining the chemical composition, the potentially digestible DM (pdDM) content of the forage was calculated using the equation: %pdDM = 0.98 (100 − %NDFap) + (%NDFap − %iNDF), where pdDM is potentially digestible DM (% DM); NDFap is neutral detergent fiber corrected for ash and protein (% DM); iNDF is indigestible neutral detergent fiber (% DM); and 0.98 is true digestibility coefficient for non-NDF components.

Forage allowance (FA) was calculated using the following equation: FA = {[((FM1 + FM2)/2)/SR]/N days} × 100, where FA is forage allowance (kg DM 100 kg^{-1} BW); FM1 is forage mass at assessment 1 (entry) (kg DM ha^{-1}); FM2 is forage mass at assessment 2 (exit) (kg DM ha^{-1}); N days is days between assessments 1 and 2; and SR is average stocking rate during the period (kg BW ha^{-1}).

Assessment of intake and digestibility

Fecal production, DM, supplement, and total DM intakes, and nutrient digestibility were measured between the 51st and 62nd day of the experimental period. To estimate fecal excretion, chromic oxide (Cr_2O_3) was administered daily at 07:00 h as candies wrapped in manila paper, at a dose of 10 g $animal^{-1}$ d^{-1}. The first 7 d were used for adaptation and to stabilize the excretion flow. Fecal sampling was conducted over the final 5 d at the following times: 16:00 h (1st day), 14:00 h (2nd day), 12:00 h (3rd day), 10:00 h (4th day), and 08:00 h (5th day). Samples were collected individually, immediately after defecation, with care to avoid contamination by foreign materials. No marker was provided on the last day of collection.

Field samples were stored at -10 °C, then pre-dried individually and ground in a Wiley mill (1 and 2 mm sieves), and stored in 250 g transparent plastic containers for later analysis.

Chromic oxide analysis followed with readings performed on an atomic absorption spectrophotometer at 550 nm. Fecal excretion (FP) was calculated according to: FP = COS/COFe, where FP is fecal production (g d^{-1}); COS is chromic oxide supplied (g d^{-1}); and COFe is chromic oxide concentration in feces (g g^{-1} DM).

Forage DM intake (FDMI) was estimated using the internal marker indigestible NDF (iNDF), after ruminal incubation (in situ) for 288 h (Detmann et al., 2012). Duplicate samples (0.5 g) of forage, supplement, and feces were placed in 5 × 5 cm non-woven fabric ('TNT') bags (20 mg cm^{-2}) and incubated. The residue was used to determine neutral detergent insoluble fiber, following the INCT method – CA F-009.1 (Instituto Nacional de Ciência e Tecnologia de Ciência Animal (INCT), Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil) (Detmann et al., 2012).

Once fecal output and iNDF concentrations were known, forage DM intake was estimated as: FDMI = {[(FE × MFe) – MSu]/MFo}, where FDMI is forage DM intake (kg d^{-1}); FE is fecal excretion (kg d^{-1}); MFe is iNDF concentration in feces (%); MSu is amount of marker (iNDF) in the supplement (kg); and MFo is marker concentration in the forage (kg kg^{-1}).

Supplement DM intake (SDMI, kg d^{-1}) was estimated using the external marker titanium dioxide (TiO_2), supplied at 15 g $animal^{-1}$ d^{-1} for 11 d, mixed with the concentrate and offered at 10:00 h: SDMI = (FE × TiO_2 Feces)/TiO_2 Supplement, where TiO_2 Feces and TiO_2 Supplement represent the TiO_2 concentrations in feces and supplement, respectively. Titanium determination was carried out according to Detmann et al. (2012) with readings on an atomic absorption spectrophotometer (Libra S22, Biochrom, Cambridge, UK).

Total daily DM intake (TDMI) was calculated by summing SDMI and FDMI: TDMI = SDMI + FDMI, where SDMI is supplement DM intake (kg d^{-1}); FDMI is forage DM intake (kg d^{-1}).

The digestibility (D) of DM and nutrients was calculated using the formula: D = [(kg nutrient ingested – kg nutrient excreted)/kg nutrient ingested] × 100.

Animal performance assessment

To determine the average daily gain (ADG) of the animals during the experimental period, two weighings were performed after a 12 h fast, one at the beginning (IBWfasting) and another at the end of the experimental period (FBWfasting). ADG = (FBWfasting + IBWfasting)/N days, where ADG is average daily gain (kg d^{-1}); IBWfasting is initial body weight at fasting (kg); FBWfasting is final body weight at fasting (kg); and N days is number of days the animals remained in the experiment.

Based on the total daily DM intake (TDMI) and the ADG, the feed conversion ratio (FCR) and its inverse, feed efficiency (FE), were calculated using the following formulas: FCR = TDMI/ADG and FE = FCR/TDMI, where FCR is feed conversion (kg DM ingested kg^{-1} gained); TDMI is total daily DM intake (kg d^{-1}); ADG is average daily gain (kg d^{-1}); and FE is feed efficiency (kg gained kg^{-1} DM ingested).

Chemical analyses

Supplement, forage, and feces samples, after being pre-dried in a forced-air oven at 60 °C for 72 h and ground in a Wiley mill to 1 mm, were analyzed for the contents of DM (INCT-CA G-003.1), mineral matter (MM) (INCT-CA M-001.1), crude protein (CP) (INCT-CA N-001.1), ether extract (EE) (INCT-CA G-004.1), neutral detergent fiber (NDF) (INCT-CA F-002.1), and corrections for protein and ash (NDFap) (INCT-CA N-004.1 and INCT-CA M-002.1, respectively); acid detergent fiber (ADF) (INCT-CA F-004.1) and its corrections for ash and protein (ADFap) (INCT-CA N-005.1 and INCT-CA M-003.1, respectively); lignin (H_2SO_4 720 g kg^{-1}; INCT-CA F-005.1); and indigestible neutral detergent fiber (iNDF) (INCT-CA F-009.1), as described in Detmann et al. (2012).

The non-fibrous carbohydrate content (NFCap), corrected for ash and protein in forage and feces, was calculated using the following formula: NFCap = 100 – (CP + EE + MM + NDFap). All terms are expressed as % of DM.

For concentrate supplements containing urea, NFCap was calculated using the following formula: NFCap = 100 - [(CP - CP from urea + Urea%) + EE + NDFap + MM], where CP is crude protein in the concentrate supplement; CP from urea is protein equivalent from urea; Urea% is urea content in the concentrate supplement; EE is ether extract; NDFap is neutral detergent fiber corrected for ash and protein; MM is mineral matter. All terms are expressed as % of DM.

The total digestible nutrient (TDN) content of the forage was calculated using the following formula: TDN = (DCP + DNDFap + DNFCap) + (DEE × 2.25), where DCP is digestible crude protein; DNDFap is digestible neutral detergent fiber (corrected); DNFCap is digestible non-fibrous carbohydrates (corrected); DEE is digestible ether extract. All values are expressed as % of DM.

Assessment of ruminal parameters

Four rumen-fistulated animals were used for rumen fluid collection. These animals were kept on the same pasture and management conditions as the others. Rumen fluid was collected immediately before supplementation (time zero), and at 2, 4, 6, and 8 h after supplementation.

Approximately 200 mL rumen fluid were collected per animal via the rumen fistula and filtered through gauze to obtain 100 mL. The pH was immediately measured using a digital potentiometer. Samples were stored in plastic containers at -5 °C.

For the determination of volatile fatty acids, 2 mL rumen fluid were added to 1 mL 25% metaphosphoric acid containing isocaproic acid as an internal standard. Samples were centrifuged for 15 min at 10 000 × g and analyzed for acetic, propionic, and butyric acids by gas chromatography using a 5890 GC (Hewlett Packard, Avondale, Palo Alto, California, USA) equipped with a 530 µm Carbowax 20 M column (Supelco, Bellefonte, Pennsylvania, USA). Oven programming: 70 °C for 1 min, 5 °C min^{-1} to 100 °C, then 45 °C min^{-1} to 170 °C, with a final hold of 5 min.

Methane (CH_4) production was estimated using the equation: CH_4 % = (Acetic acid × 0.45) − (Propionic acid × 0.275) + (Butyric acid × 0.40).

Statistical analysis

The data were analyzed using the SAS program (SAS Institute, Cary, North Carolina, USA). Outliers were removed, and residuals were tested for normality and homogeneity of variances. When necessary, data were transformed using the inverse square root. The mathematical model used was $Y_{ij} = \mu + H_j + e_{ij}$, where Y_{ij} is value referring to the observation of the replicate i of the treatment j, µ is overall average, H_j is effect of treatment j (0.2%, 0.3%, 0.4%, and 0.5% BW) and e_{ij} is random error associated with observation. Dependent variables were analyzed by ANOVA with decomposition of orthogonal polynomial contrasts for linear or quadratic fits based on supplementation levels. A significance level of 5% ($P < 0.05$) was adopted, with trends considered for values between 5% and 10% ($0.05 > P < 0.10$).

Ruminal parameters were analyzed using a 4×4 Latin square with repeated measures in a factorial arrangement. The model included fixed effects (treatment: 0.2%, 0.3%, 0.4%, and 0.5% BW; and sampling times: 0, 2, 4, 6, and 8 h post-supplementation) and their interaction, with animal and period as random effects. Significance was declared at 5% to 10% ($0.05 > P < 0.10$).

RESULTS

The average availability of forage DM was 4867 kg ha^{-1}, of which approximately 75% was potentially digestible (Table 2). Green DM accumulated to 3837 kg ha^{-1}, resulting from the sum of the available DM in stem, leaf, and sheath.

Table 2. Evaluation of *Megathyrsus maximus* 'Mombaça' forage in the experimental period.

	Mean
Total DM availability, kg ha^{-1}	4867.63
Availability of potentially digestible DM, kg ha^{-1}	3668.04
Forage allowance, kg DM 100 kg^{-1} BW d^{-1}	13.63
Stem DM availability, kg ha^{-1}	2047.06
Leaf DM availability, kg ha^{-1}	1790.92
Senescent material DM availability, kg ha^{-1}	1029.65
Leaf:Stem ratio	0.87

The intakes of total DM and supplement increased ($P < 0.05$) with increasing supplementation levels in the heifers' diet; however, no effect was observed on forage DM intake (Table 3).

There were increases ($P < 0.05$) in the intake of OM, CP, EE, and NFC with increasing supplementation. In contrast, the intakes of NDFap and TDN were not affected ($P > 0.05$) by the supplementation levels.

Increasing supplementation levels did not influence ($P > 0.05$) the apparent digestibility of DM, OM, EE, or NFC. However, there was a linear decrease ($P < 0.05$) in the digestibility of NDFap and a quadratic increase ($P < 0.05$) in the apparent digestibility of CP in the heifers' diet with increasing supplementation.

The concentrations of acetate, propionate, total volatile fatty acids, and the acetate:propionate ratio in the rumen fluid decreased ($P < 0.05$) with increasing supplementation, whereas butyrate and rumen pH were not affected ($P > 0.05$) by the supplementation levels. No interaction ($P > 0.05$) was observed between supplementation level and collection time for any of the ruminal parameters evaluated (Table 4).

The average daily gain of the heifers was 0.64 kg d^{-1}, resulting in a final body weight of 398 kg at the end of the finishing period. Neither variable was influenced ($P > 0.05$) by the supplementation levels (Table 5).

Table 3. Intake and apparent digestibility of nutrients in the diet of heifers finished on *Megathyrsus maximus* 'Mombaça' pasture with increasing levels of concentrate supplementation. BW: Body weight; SEM: standard error of the mean; *P*-value: significant probability at the 5% level; L: linear; Q: quadratic; NDFap: neutral detergent fiber corrected for ash and protein; NFC: non-fibrous carbohydrates; TDN: total digestible nutrient. Regression equation: [a]Y = 5.36849 + 6.85171x (r^2 = 0.80); [b]Y = 1.5349 + 1.871x (r^2 = 0.836); [c]Y = -0.0696453 + 3.29237x (r^2 = 0.99); [d]Y = 4.29012 + 5.4563x (r^2 = 0.81); [e]Y = 0.8072 + 0.913x (r^2 = 0.9982); [f]Y = 0.0683492 + 0.166769x (r^2 = 0.76); [g]Y = 0.657571 + 2.12924x (r^2 = 0.86); [h]Y = 56.721 + 132.76x - 205.69x² (r^2 = 0.9069); [i]Y = 111.96 - 353.14x + 503.95x² (r^2 = 0.999); [j]Y = 65.6831 - 22.148x (r^2 = 0.83).

	Supplementation level (% BW)					*P*-value	
	0.2	0.3	0.4	0.5	SEM	L	Q
Intake, kg d^{-1}							
Total DM	7.0	7.4	7.5	9.2	0.2949	0.0079[a]	0.2479
Total DM, % BW	2.0	2.1	2.1	2.6	0.0846	0.0123[b]	0.3463
Forage DM	6.3	6.5	6.3	7.6	0.2134	0.1057	0.2488
Forage DM, % BW	1.8	1.8	1.8	2.1	0.0626	0.1434	0.0618
Supplement DM	0.6	0.9	1.2	1.6	0.1016	0.0001[c]	0.6588
Organic matter	5.6	5.9	6.0	7.3	0.2355	0.0081[d]	0.2648
Crude protein	1.0	1.1	1.2	1.3	0.0472	0.0332[e]	0.9957
Ether extract	0.1	0.1	0.1	0.2	0.0056	0.0002[f]	0.0526
NDFap	4.3	4.4	4.4	5.3	0.1482	0.0696	0.0646
NFC	1.1	1.3	1.4	1.8	0.0718	0.0004[g]	0.1798
TDN	4.3	4.5	4.3	5.2	0.1679	0.0671	0.3090
Apparent digestibility, %							
Dry matter	56.5	58.4	57.6	56.6	0.4514	0.9132	0.1238
Organic matter	62.3	63.34	62.9	61.4	0.4965	0.5115	0.2181
Crude protein	75.4	77.0	77.9	71.3	0.7926	0.0903	0.0038[h]
Ether extract	61.4	51.6	51.1	61.4	1.5854	0.9775	0.0011[1]
NDFap	61.2	60.1	55.0	55.5	0.7928	0.0009[j]	0.5639
NFC	60.9	69.4	63.4	63.5	1.7824	0.9111	0.2475

Table 4. Rumen pH, estimated production of enteric methane (CH_4) and volatile fatty acids (mmol L^{-1}) from the rumen of heifers finished on *Megathyrsus maximus* 'Mombaça' pasture with increasing levels of concentrate supplementation. BW: Body weight; SEM: standard error of the mean; *P*-value: Significant probability at the 5% level: L: linear; Q: quadratic; TVFA: total volatile fatty acids; A:P ratio: acetate:propionate ratio. Regression equation: [a]Y = 6.3956 - 0.0446x (r^2 = 0.7258); [b]Y = 17.771 + 1.0982x - 0.1495x² (r^2 = 0.6004); [c]Y = 39.822 + 2.3712x - 0.321x² (r^2 = 0.5865); [d]Y = 6.9161 + 0.1609x (r^2 = 0.4528); [e]Y = 51.142 + 2.5336x - 0.3864x² (r^2 = 0.5996); [f]Y = 45.915 - 22.495x (r^2 = 0.9023); [g]Y = 10.193 - 7.5237x (r^2 = 0.8433); [h]Y = 60.473 - 29.121x (r^2 = 0.8887); [i]Y = 2.3918 + 16.82x - 21.15x² (r^2 = 0.8835); [j]Y = 19.885 - 8.3416x (r^2 = 0.8836).

	Supplementation level (% BW)					*P*-value			Contrast	
	0.2	0.3	0.4	0.5	SEM	Level	Time	Level × Time	L	Q
pH	6.25	6.12	6.31	6.18	0.0372	0.1291	0.0006[a]	0.9628	0.9467	0.971
CH_4	18.33	17.44	15.98	16.05	0.3585	0.0135	0.0009[b]	0.7780	0.0022[f]	0.440
Acetate	41.37	39.89	35.58	35.31	0.8171	0.0012	0.0008[c]	0.8357	0.0002[g]	0.6299
Propionate	9.06	7.55	6.85	6.78	0.3069	0.0006	0.0340[d]	0.9175	0.0001[h]	0.0815
Butyrate	5.01	4.03	4.16	5.07	0.3049	0.4104	0.4674	0.8854	0.9056	0.0941
TVFA	55.41	51.47	47.07	47.17	1.1949	0.0052	0.0024[e]	0.8616	0.0008[i]	0.2773
A:P ratio	4.86	5.68	5.58	5.56	0.1212	0.0071	0.6453	0.8636	0.0157[j]	0.0230

Table 5. Performance of heifers finished on *Megathyrsus maximus* 'Mombaça' pasture with increasing levels of concentrate supplementation. BW: Body weight; SEM: standard error of the mean; *P*-value: Significant probability at the 5% level; L: linear; Q: quadratic; AU: animal unit. Regression equation: [a]Y = 8.498 + 10.78x (r^2 = 0.7831); [b]Y = 0.1106 - 0.0718x (r^2 = 0.9261).

	Supplementation level (% BW)					*P*-value	
	0.2	0.3	0.4	0.5	SEM	L	Q
Initial body weight, kg	312.7	312.9	311.6	313.4	3.5571	0.9809	0.9145
Final body weight, kg	398.1	397.1	393.6	403.2	4.9086	0.7965	0.6049
Average daily gain, kg d^{-1}	0.64	0.63	0.61	0.67	0.0238	0.7271	0.4982
Feed conversion, kg kg^{-1}	11.3	10.9	12.4	14.4	0.4999	0.0134[a]	0.1972
Gross feed efficiency	0.10	0.09	0.09	0.07	0.0037	0.0309[b]	0.6861
Stocking rate, AU ha^{-1}	1.5	1.5	1.5	1.5	0.0168	0.8889	0.6912

DISCUSSION

In supplementation studies, pasture characteristics are essential to understanding animal performance responses (Fernandes et al., 2022). In the present study, total DM availability reached 4867 kg ha^{-1}, exceeding the 4500 kg ha^{-1} threshold recommended by Paulino et al. (2008) for tropical pastures to ensure satisfactory performance and prevent intake restrictions. Additionally, the forage allowance was 13.63 kg DM 100 kg^{-1} BW d^{-1}, above the minimum threshold predicted by Silva et al. (2009) for maintaining adequate forage supply in tropical conditions. Beyond quantity, pasture quality—indicated by green DM and potentially degradable DM—averaged 3837 and 3668 kg ha^{-1}, respectively, ensuring the nutritional adequacy of the forage available to the animals (Pereira et al., 2022).

The increase in total DM intake by heifers was likely due to the greater intake of the concentrate supplement. The enhanced availability of concentrate in the trough stimulated consumption (Lins et al., 2022). Nonetheless, no substitution effect was observed, as forage DM intake remained unchanged (Barbero et al., 2021). Similarly, Rocha et al. (2019) also reported increased total DM and supplement intake in finishing cattle on pasture with higher supplementation levels.

The stable forage intake across supplementation levels can be attributed to the stable chemical composition of the pasture (Pereira et al., 2022), along with the high availability of green DM and forage allowance, which allowed animals to selectively graze more nutrient-rich components such as leaves (Barroso et al., 2024). Supplementation may also increase forage intake when the total digestible nutrient (TDN)/crude protein (CP) ratio of the pasture exceeds 70.0 g kg^{-1} (Barbizan et al., 2020). However, in the present study, this ratio was only 43.5 g kg^{-1}, explaining the absence of increased forage intake even at higher supplementation levels (Figueiras et al., 2016).

The concentrate supplement consistently contained higher levels of CP (307 to 570 g kg^{-1}) and non-fibrous carbohydrates (NFC) (570 to 634 g kg^{-1}) compared to pasture (102 g kg^{-1} CP and 110 g kg^{-1} NFC). Thus, the increased intake of the supplement accounts for the observed rise in CP and NFC intakes by the heifers. Neves et al. (2018) also observed increased NFC intake, but not CP, with rising levels of concentrate supplementation in steers grazing tropical pasture.

The increases in CP and NFC intakes were not sufficient to influence the digestibility of DM and organic matter (OM) in the heifers' diets. Possibly, the greater supply of N and degradable OM in the rumen, and their ratio, were not adequate to consistently alter degradation kinetics or ruminal disappearance rates of DM (Chen et al., 2022), and therefore did not affect the apparent digestibility of DM and OM in the heifers' diets. Franco et al. (2021) elegantly demonstrated that pasture quality, supplement type (energy or protein), and their interactions modulate ruminal degradation responses and animal performance on tropical pastures. Similarly, Dueñez et al. (2025) also reported no changes in the apparent digestibility of DM and OM with increasing supplementation levels in cattle on tropical pasture.

With increasing supplementation levels, the composition of the supplement offered to the animals changed: Corn grain content increased (from 49% to 86% of the supplement's DM), while soybean meal (from 31% to 6.7% DM) and urea (from 14% to 4.5% DM) decreased. These changes may have influenced CP digestibility, which initially improved with the higher supply of non-protein N from urea (Wahyono et al., 2022), but tended to decrease due to the increasing presence of rumen undegradable protein (e.g., prolamins) provided by corn grain (Gholizadeh et al., 2021), especially at the highest supplementation level (0.5% BW). Barbizan et al. (2020) also observed a quadratic effect on crude protein digestibility with increasing supplementation in Nellore × Angus crossbred bulls.

The 75% increase in corn grain inclusion in the supplement, accompanying higher supplementation levels, may also explain the observed decrease in neutral detergent fiber corrected for ash and protein (NDFap) digestibility. The greater starch intake, mainly from corn, reduced ruminal neutral detergent fiber (NDF) degradability (Hall and Mertens, 2017), thereby compromising NDFap digestibility in the total diet. In this regard, Marques et al. (2019) reported changes in the ruminal population of fiber-degrading microorganisms with increased protein in cattle supplements. Similarly, (Barroso et al., 2025) found a quadratic reduction in NDFap digestibility in steers finished on pasture with increasing supplementation levels.

The reduction in NDFap digestibility may also help explain the decreases in concentrations of total fatty acids, acetate, and propionate in the rumen fluid with increasing supplementation (Schulze et al., 2017). The NDFap is the main fraction of digestible OM in the rumen of pasture-finished animals (Detmann et al., 2024). In this study, NDFap intake accounted for more than 70% of the heifers' OM intake. Therefore, any factor affecting NDFap degradation in the rumen can significantly impact the concentration of volatile fatty acids, especially acetate and propionate (Zhang et al., 2024). Supporting this, the reduced acetate:propionate ratio observed may indicate a decline in ruminal fermentation of OM.

Despite the 1 kg d^{-1} increase in concentrate supplement intake, no changes were observed in the final body weight or average daily gain of heifers. It is likely that pasture availability, in both quantity and quality, provided the necessary nutrients to sustain an average performance of approximately 0.65 kg d^{-1}, even at the lowest supplementation level (Mota et al., 2024). Moreover, Clariget et al. (2021) and Tambara et al. (2021) noted that the response of cattle finished on tropical pasture to supplementation level varies according to pasture quality and availability. Additionally, animals may have shown limited response to increased concentrate levels due to their physiological status approaching sexual maturity (Purwin et al., 2023). Heifers particularly tend to deposit more fat and reduce muscle accretion rates (Lancaster, 2025), making them less responsive to intensive nutritional plans compared to animals in growth or puberty. Santos et al. (2019) also found no effect of increased supplementation levels on the average daily gain of heifers finished on pasture during the rainy season.

CONCLUSIONS

Increasing concentrate supplementation from 0.2% to 0.5% of body weight for heifers finished on *Megathyrsus maximus* 'Mombaça' pasture increases nutrient intake and reduces ruminal production of volatile fatty acids, but does not affect average daily gain. Therefore, we recommend the more modest supplementation level (0.2% body weight) for heifers finished on 'Mombaça' pasture during the rainy season in the tropics. Further studies, particularly involving other animal categories (e.g., steers, cull cows) and different forage allowances, are needed to strengthen the evidence base for finishing cattle on tropical pasture.

Author contribution

Conceptualization: F.F.S. Methodology: T.R.P., J.W.D.S., L.S.F.G. Software: L.V.S. Validation: M.M.O.G., B.O.C. Formal analysis: T.L.A.C.A. Investigation: F.Z-P. Resources: B.L. Data curation: A.P.G.S. Writing-original draft: D.M.L.J. Writing-review & editing: D.M.L.J. Visualization: T.R.P., J.W.D.S., L.S.F.G. Supervision: L.V.S. Project administration: R.R.S. Funding acquisition: R.R.S. All co-authors reviewed the final version and approved the manuscript before submission.

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