

Intake, digestibility, performance, and compensatory gain of post-weaned Guzolando (Guzerat × Holstein) heifers raised on tropical pasture

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Received: 31 May 2025; Accepted: 4 September 2025; doi:10.4067/S0718-58392025000600873

ABSTRACT

Compensatory growth results from a heightened conversion of nutrients from the diet into components of the animal's body, and can be achieved through compensatory nutrition interspersed with a period of scarcity or nutritional stress. The aim of this study was to assess the impact of compensatory nutrition on the intake, apparent digestibility, weight gain, feed conversion, and compensatory gain of post-weaning Guzolando heifers on tropical pasture. Twenty crossbred heifers (5/8 dairy Guzerat × 3/8 Holstein), aged 12 mo and weighing 187 ± 13.74 kg, were used in the study. The heifers were divided into two groups: Control receiving a concentrate supplement (CS) to meet 100% nutrient requirements and compensatory nutrition (CN) receiving a CS to meet 80% nutrient requirements during the restriction period and 120% nutrient requirements during the realimentation period. Nonsignificant effect of CN on the average nutrient intake by heifers was observed. With the exception of ether extract, there was also nonsignificant effect ($P > 0.05$) of CN on the apparent digestibility of dietary nutrients by the heifers. Compensatory nutrition did not influence ($P > 0.05$) average daily gain with mean values of 726.8 and 737.9 g d⁻¹ for the control and CN heifers, respectively. Animals subjected to the CN regime exhibited complete compensatory weight gain, without impacting the intake and digestibility of the nutritional components of the diet.

Key words: Compensatory nutrition, feed restriction, realimentation, replacement heifers.

INTRODUCTION

The post-weaning phase plays a crucial role in replacement heifers, significantly impacting bovine milk production systems. This importance arises mainly from the continuous need to replace cows with younger, more productive, and adapted animals (Zanton and Heinrichs, 2005). In pasture-based milk production systems, post-weaning presents additional challenges, particularly in overcoming obstacles related to the availability and nutritional value of forage throughout the year. These challenges include the reduced weight gain of animals and consequent delays in entering reproductive and productive activity (Castro et al., 2023).

To address these challenges, pasture supplementation strategies aim to mitigate the impact of variations in the nutritional value of pasture on animal performance (Barroso et al., 2025). These strategies involve using concentrate feed as supplements to meet the requirements of post-weaned animals grazing on pasture (Nieman

et al., 2023). However, the availability and cost of concentrate inputs (i.e., grains, meals, and by-products) used to supplement grazing animals, also fluctuate. They tend to become more expensive and less available during the dry season in tropical areas (Ashfield et al., 2014). Therefore, implementing strategies that involve restricting the supply of nutrients to animals during specific periods and subsequently refeeding the herd with nutrients exceeding the animals' requirements (i.e., compensatory nutrition) becomes an interesting approach for the post-weaning phase of grazing dairy heifers in tropical regions. This approach takes into account the varying availability and nutritional value of pasture and supplements, offering a potential solution to enhance the efficiency of post-weaning management in the tropics.

Compensatory growth results from a heightened conversion of nutrients from the diet into components of the animal's body, and can be achieved through compensatory nutrition interspersed with a period of scarcity or nutritional stress (Lawrence et al., 2012; Monari-DeLucia et al., 2016). In the tropics, compensatory gain naturally occurs due to the seasonal cycle of droughts and rains. Nonetheless, its effect varies depending on the genotype, physiological stage of the animal, and the intensity and/or duration of the restriction and realimentation (Imaz et al., 2022). While there is a consensus that periods of scarcity and realimentation at grazing can significantly influence heifers' development and entry into reproductive activity (Roche et al., 2015; Henley et al., 2021), factors such as the type of restriction (energy or protein), animal age (Hennessy and Morris, 2003), and genotype (i.e., weight at maturity) (Keady et al., 2021) significantly influence compensatory gain in cattle.

In this context, limited information exists on the compensatory gain of heifers from crosses between taurine (*Bos taurus*) and zebu (*Bos indicus*) breeds, particularly in post-weaning animals derived from the Guzerat breed (large frame size) on tropical pasture during the dry and rainy seasons (Busanello et al., 2021).

Our hypothesis posited that a period of restriction (80% of the supplement to meet protein and energy requirements) followed by an equal period of realimentation (120% of the supplement to meet protein and energy requirements) does not influence the average performance or final body weight of post-weaned Guzolando heifers on tropical pasture. Therefore, the objective was to examine whether compensatory nutrition affects the intake, apparent digestibility, weight gain, feed conversion, and compensatory gain of post-weaned Guzolando heifers on tropical pasture.

MATERIAL AND METHODS

All experimental procedures complied with the Ethics Committee on Animal Use (license 017/2012, Ethics Committee on Animal Use/Universidade Estadual do Sudoeste da Bahia, UESB, Bahia, Brazil).

Locations, animals, and treatments

The experiment took place in the municipality of Ribeirão do Largo (15°26'46" S, 40°44'24" W; 800 m a.s.l.), Bahia, Brazil. The region experiences a tropical climate with a dry season type Aw, as classified by Köppen-Geiger. A total of 20 Guzolando heifers (5/8 dairy Guzerat × 3/8 Holstein) were involved, starting with an average age of 12 mo and an initial body weight of 187 ± 13.74 kg. All animals underwent treatment against ecto- and endoparasites and were placed in a 10 ha experimental area that was divided into four paddocks of 2.5 ha each. The paddocks featured uniform ground cover of *Urochloa brizantha* 'Marandú'. The study lasted 238 d, with 14 d dedicated to pasture adaptation and experimental management and 224 experimental days further divided into four periods of 56 d each: Period 1 (restriction), Period 2 (realimentation), Period 3 (restriction), and Period 4 (realimentation).

Two treatments were administered: Control treatment, in which heifers received a concentrate supplement (equivalent to 2.5% of live weight) to meet 100% of the total digestible nutrients (TDN) and crude protein (CP) requirements for a weight gain of 750 g d^{-1} (NRC, 2016); and the compensatory nutrition (CN) treatment, involving heifers alternating between restriction (80% TDN and CP requirements for a weight gain of 750 g d^{-1}) and realimentation (120% TDN and CP requirements for a weight gain of 750 g d^{-1}). The formulated concentrate supplement (Table 1) aimed to meet the animals' requirements for weight maintenance and a gain of 750 g d^{-1} (NRC, 2016), with a total estimated intake of $2.5 \text{ kg DM } 100 \text{ kg}^{-1}$ live weight, adjusted per treatment. Supplementation occurred daily at 10:00 h in uncovered collective plastic troughs with double access and a linear dimension of $80 \text{ cm animal}^{-1}$. Both treatments were distributed in a completely randomized design across the 20 animals, resulting in 10 replicates per treatment.

The two groups of heifers (Control and CN) were managed in a grazing system employing rotated stocking, utilizing two paddocks simultaneously with an occupancy period of 28 d and a rest period of 28 d. To minimize paddock influence, aside from maintaining the same animal load, the groups were alternated between the two paddocks every 7 d. Following 28 d of simultaneous use, both groups of heifers were moved to two other paddocks, and the described management cycle was restarted.

Table 1. Proportion of ingredients and chemical composition of concentrate supplements used in the experimental periods. ¹Provided per 1 kg: Ca 140 g; P 65 g; Na 148 g; Mg 5 g; S 12 g; Co 107 mg; Cu 1,550 mg; I 150 mg; Mn 1400 mg; Ni 30 mg; Se 18 mg; Zn 4500 mg; F (maximum) 650 mg. ²Non-fibrous carbohydrates. ³Neutral detergent fiber corrected for ash and protein. ⁴Acid detergent fiber. ⁵Total digestible nutrients.

	Period 1 (Restriction)	Period 2 (Realimentation)	Period 3 (Restriction)	Period 4 (Realimentation)
Ground corn grain, %	28.20	66.47	70.52	72.05
Soybean meal, %	34.08	26.75	25.92	25.21
Wheat bran, %	35.20	5.28	0.08	-
Calcitic limestone, %	1.32	-	0.67	0.84
Dicalcium phosphate, %	-	-	0.51	-
Urea, %	-	-	-	0.36
Mineral mixture ¹ , %	1.20	1.50	2.30	1.54
DM, g kg ⁻¹ as fed	912.30	905.60	904.50	907.60
Ash, g kg ⁻¹ DM	49.50	50.50	50.30	51.50
Crude protein, g kg ⁻¹ DM	225.60	202.60	194.90	202.00
Ether extract, g kg ⁻¹ DM	28.90	26.70	34.50	36.50
NDFap ³ , g kg ⁻¹ DM	153.10	174.80	160.80	168.80
NFC ² , g kg ⁻¹ DM	587.10	574.20	556.50	548.30
ADF ⁴ , g kg ⁻¹ DM	48.90	51.10	51.70	55.20
TDN ⁵ , g kg ⁻¹ DM	771.90	816.30	805.00	812.00

Pasture attributes

The pasture underwent evaluation every 28 d. To estimate forage availability and other attributes (Table 2), 12 samples were taken per paddock, clipped at ground level with a 0.25 m² frame. Samples were weighed on a portable scale with 5 g accuracy, then combined to create a composite sample of the grazed paddocks and another of the ungrazed paddocks. Duplicate samples were taken, with one placed in a plastic bag, labeled, and frozen at -10 °C for chemical analysis, and the other used for manual separation of components (leaf, stem, and dead material). The separated components were weighed to determine the percentage of each, then stored in labeled plastic bags and frozen at -10 °C for subsequent chemical analysis. The percentage of each component in the forage mass was calculated based on DM of each component's sample divided by DM of the total sample.

The accumulation of DM during different experimental periods was calculated by multiplying the daily DM accumulation rate (DAR) by the number of days in the period. Daily residual biomass (DRB) of DM was estimated in the two paddocks using the double-sampling method. Before clipping, DM of the sample's biomass was visually estimated. The values from the visually estimated and clipped samples were used when the frame was thrown 50 times. Forage allowance (FA) was determined using the formula below: $FA = \{[(DRB \times \text{Area in kg DM ha}^{-1} \text{ d}^{-1}) + DAR \times \text{Area in kg DM ha}^{-1} \text{ d}^{-1}] / \text{Total body weight of animals, kg ha}^{-1}\} \times 100$.

The potentially digestible DM in the pasture was estimated according to equation (potentially digestible DM = 0.98 (100 - Neutral detergent fiber %) + (Neutral detergent fiber % - Insoluble neutral detergent fiber %)).

Table 2. Chemical composition (simulated grazing) and forage availability during the experimental periods. ¹Non-fibrous carbohydrates. ²Neutral detergent fiber corrected for ash and protein. ³Acid detergent fiber. ⁴Total digestible nutrients. ⁵Potentially digestible DM. ⁶Animal units. ⁷Body weight.

Chemical composition	Period 1 (Restriction)	Period 2 (Realimentation)	Period 3 (Restriction)	Period 4 (Realimentation)
DM, g kg ⁻¹ as fed	274.5	253.4	400.5	248.7
Ash, g kg ⁻¹ DM	57.8	60.9	62.0	58.9
Crude protein, g kg ⁻¹ DM	122.3	110.9	87.8	151.3
Ether extract, g kg ⁻¹ DM	26.5	27.6	23.5	26.9
NFC ¹ , g kg ⁻¹ DM	207.8	185.6	147.8	173.4
NDFap ² , g kg ⁻¹ DM	720.8	757.3	783.9	677.5
ADF ³ , g kg ⁻¹ DM	320.5	349.8	376.2	309.7
TDN ⁴ , g kg ⁻¹ DM	690.7	683.5	587.9	678.9
Forage availability				
Total DM availability, kg ha ⁻¹	3474.0	2967.0	1910.0	3898.0
Green DM availability, kg ha ⁻¹	2758.0	1902.0	1266.0	2158.0
pdDM ⁵ , kg ha ⁻¹	2686.0	2207.0	1193.0	2898.0
Stocking rate, AU ⁶ ha ⁻¹	0.92	1.12	1.28	1.38
Forage allowance, kg DM 100 kg ⁻¹ BW ⁷ d ⁻¹	33.0	26.0	8.0	39.0
% Leaf	40.3	24.2	24.3	43.3
% Stem	39.1	39.9	42.0	36.3
% Senescent material	20.6	35.9	33.7	20.4
Leaf:Stem ratio	1.03	0.61	0.58	1.19

Chemical analysis

Forage samples were utilized for estimating nutrient intake and apparent digestibility coefficients. Concentrate supplement samples were collected in each period, and at the experiment's conclusion, a composite of all materials was created. Both supplement and forage samples were dried in a forced-air oven at 55 °C and ground in a Wiley mill to 1 mm for subsequent chemical analyses.

Dry matter (DM), ash, crude protein (CP), and ether extract (EE) contents were determined according to the AOAC (1990) methodology. Neutral and acid detergent fibers were determined following the method of Van Soest (1964). Neutral detergent fiber was corrected for ash and protein (FDNp) through procedures proposed by Licitra et al. (1996). Non-fibrous carbohydrates were determined also free of ash and protein (NFCap), by the following equation: $NFCap = 100 - \text{ash} - CP - EE - NDFap$. Because the supplement contained urea, its NFCap content was determined by the following equation: $NFCap = 100 - MM - EE - NDFap - (CP - CPu + U)$, where CPu is CP in urea; and U is urea content. Total digestible nutrients (TDN) were calculated using the equation $TDN\% = DCP + DNDFap + DNFC + 2.25 DEE$, where DCP is digestible CP; DNDFap is digestible NDFap; DNFC is digestible NFC; and DEE is digestible EE.

Intake and apparent digestibility

Estimates of fecal output, intake, and apparent digestibility were conducted between the 44th and 56th experimental days of each period. Chromic oxide served as an external marker for fecal output estimation, supplied daily at 09:00 h in a single dose of 10 g packed in a paper bag for 12 consecutive days. Fecal collection occurred over 5 d from the eighth to the 20th day, following 7 d of adaptation and marker excretion flow regulation. During the periods of chromic oxide supply, all animals were gathered daily in the corral at 08:30 h, placed in a collective compartment, and then in a squeeze chute. The cartridge was supplied manually, without restraint, orally. Feces were collected once a day, in the same paddock, consistently after concentrate consumption, immediately following defecation. Post-collection, the frozen feces were pre-dried (55 °C for 72 h) and ground in a Wiley mill for subsequent chemical composition analyses, as described in the previous topic. The quantification of chromic oxide followed the methodology of Detmann et al. (2012), with reading performed on an atomic absorption spectrophotometer, Avanta Sigma SavantAA (GBC, Keysborough Victoria, Australia).

Subsequently, fecal output and internal marker indigestible neutral detergent fiber (iNDF) were known, it was possible to estimate forage DM intake using the equation: Forage DM intake (kg d^{-1}) = $\{[(\text{Fecal output, kg d}^{-1} \times \text{Concentration of marker (iNDF) in feces, \%}) - \text{Quantity of the marker (iNDF) in the concentrate supplement, kg}]/\text{Concentration of marker (iNDF) in the forage, kg kg}^{-1}]\}$.

The intake of forage DM was estimated utilizing the iNDF, obtained after ruminal incubation for 288 h (Detmann et al., 2012). Duplicate samples of 0.5 g each from forage, supplement, and feces were subjected to ruminal incubation using bags made of non-woven fabric (TNT) with a grammage of 20 mg cm^{-2} and dimensions of $5 \times 5 \text{ cm}$. Following incubation, the remaining material underwent extraction with neutral detergent to determine iNDF. Upon obtaining the values for fecal output and iNDF, the estimation of forage DM intake was calculated using the following equation: Forage DM intake (kg d^{-1}) = $\{[(\text{Fecal output, kg d}^{-1} \times \text{Concentration of marker (iNDF) in feces, \%}) - \text{Quantity of marker in the concentrate supplement, kg}]/\text{Concentration of marker in the forage, kg kg}^{-1}]\}$.

Supplement DM intake was estimated using the external marker titanium dioxide (TiO_2) at a rate of $15 \text{ g animal}^{-1} \text{ d}^{-1}$. The marker was mixed with the concentrate for 11 d and supplied directly in the trough. The following equation was employed: Supplement DM intake (kg d^{-1}) = $[(\text{Fecal output, kg d}^{-1} \times \text{Concentration of marker (TiO}_2\text{) in feces, \%})/\text{Concentration of marker in the supplement, \%}]$.

Quantification of titanium dioxide followed the methodology of Detmann et al. (2012), and with readings conducted on an atomic absorption spectrophotometer (Libra S22; Biochrom, Cambridge, UK). Apparent nutrient digestibility was determined using the formula: $D = [(\text{kg nutrient intake} - \text{kg nutrient output})/\text{kg nutrient intake}] \times 100$.

Performance and compensatory gain

Total weight gain was determined by the difference between the final weight and initial weight. Average daily gain (ADG) was calculated as the ratio between total weight gain (kg) and period (d). Feed conversion was determined as the ratio between DM intake (kg) and ADG (kg). The animals were weighed at the beginning and end of the experiment, as well as every 56 d, to calculate requirements and adjust the concentrate supplement to meet the expected gain. Compensatory gain was determined using the formula of Wilson and Osbourne (1960): $\text{CG (\%)} = 100 \times (A - B)/A$, where CG is compensatory gain in percentage terms, indicating full recovery of the value lost during restriction when $\text{CG} = 100\%$; A is difference between the final body weights (FBW, kg) of animals under restriction and control animals at the end of the restriction period; and B is difference between the FBW (kg) of animals under restriction and control animals at the end of the realimentation period.

Statistical analysis

The experimental period consisted of four periods, with two under restriction and two under realimentation. To assess compensatory nutrition, data were grouped into two periods, combining the averages of the 1st and 3rd periods for the restriction phase and the averages of the 2nd and 4th periods for the realimentation phase. Statistical interpretation of results was conducted through ANOVA and F test at a 0.05 probability level using SAEG software (UFV, Viçosa, Minas Gerais, Brazil). The statistical model employed is expressed as: $Y_{ijk} = \mu + T_i + e_{ijk}$, where: Y_{ijk} is the observed value of the variable; μ is overall mean; T_i is effect of treatment i th; e_{ijk} is error associated with each observation.

RESULTS

Heifers subjected to compensatory nutrition (CN) exhibited a 7.2% lower ($P < 0.05$) intake of supplement DM and, consequently, lower ($P < 0.05$) intakes of crude protein (CP) (-9.3%), non-fibrous carbohydrates (NFC) (-14.7%), total digestible nutrients (TDN) (-7.71%), and energy during restriction periods compared to control animals. In contrast, during realimentation, CN heifers consumed 19.9% more ($P < 0.05$) supplement DM and 18.1% less ($P < 0.05$) forage DM than control heifers. Consequently, CN heifers showed a lower intake of neutral detergent fiber (NDF) and a higher NFC intake during realimentation. Nonsignificant effect ($P > 0.05$) of compensatory nutrition on overall nutrient intake was observed when evaluating all periods (Table 3).

Table 3. Nutrient intake of post-weaned heifers under no restriction (control) or receiving compensatory nutrition (CN) on tropical pasture while supplemented with concentrate in periods of restriction and realimentation and the average of periods. SDM: Standard deviation of the mean. ¹Percentage of body weight. Means in the same row and in the same period followed by different letters, differ from each other according to the F test ($\alpha = 5\%$). OM: Organic matter; CP: crude protein; EE: ether extract; NDF: neutral detergent fiber; NFC: non-fibrous carbohydrates; TDN: total digestible nutrients; DE: Digestible energy; ME: metabolizable energy.

	Restriction			Realimentation			Average of periods		
	Control	CN	SDM	Control	CN	SDM	Control	CN	SDM
Total DM, kg d ⁻¹	5.20	4.98	0.244	5.96	5.91	0.386	5.58	5.44	1.411
Total DM, %BW ¹	2.05	1.99	0.103	2.05	2.05	0.096	2.05	2.02	0.232
Forage DM, kg d ⁻¹	2.78 ^b	3.03 ^a	0.247	3.25 ^a	2.66 ^b	0.384	3.02	2.85	1.465
Forage DM, %BW	1.04 ^b	1.17 ^a	0.076	1.09 ^a	0.89 ^b	0.101	1.07	1.03	0.411
Supplement DM, kg d ⁻¹	2.60 ^a	2.41 ^b	0.125	2.71 ^b	3.25 ^a	0.149	2.65	2.83	1.233
Supplement DM, %BW	1.01 ^a	0.82 ^b	0.059	0.95 ^b	1.15 ^a	0.066	0.98	0.99	0.231
OM, kg d ⁻¹	4.95	4.78	0.248	5.69	5.59	0.384	5.32	5.18	1.407
CP, kg d ⁻¹	0.75 ^a	0.68 ^b	0.022	0.99	1.03	0.052	0.87	0.85	0.224
EE, kg d ⁻¹	0.19 ^a	0.18 ^b	0.009	0.22	0.22	0.013	0.20	0.20	0.094
NDF, kg d ⁻¹	2.69	2.78	0.194	2.81 ^a	2.49 ^b	0.268	2.75	2.64	1.019
NFC, kg d ⁻¹	1.56 ^a	1.33 ^b	0.023	1.94 ^b	2.17 ^a	0.051	1.75	1.75	0.350
TDN, kg d ⁻¹	3.37 ^a	3.11 ^b	0.185	3.79	3.88	0.242	3.58	3.49	0.569
DE, Mcal d ⁻¹	14.88 ^a	13.70 ^b	0.815	16.72	17.10	1.065	15.80	15.40	2.512
ME, Mcal d ⁻¹	12.20 ^a	11.23 ^b	0.668	13.71	14.02	0.873	12.95	12.63	2.059

The apparent digestibility of CP (-4.4%) and NFC (-12.6%) as well as the TDN content (-3.5%) of the diet in CN heifers during restriction periods were lower ($P < 0.05$) than those observed in control heifers. In contrast, the apparent digestibility of NDF in the diet of CN heifers was 8% higher ($P < 0.05$) than in control animals during the restriction period. There was a reduction ($P < 0.05$) in the apparent digestibility of DM (-7.6%), OM (-7.9%), CP (-6.4%), NDF (-12.8%), and NFC (6.3%) from the diet fed to CN heifers during realimentation. Nevertheless, the TDN content of the diet of CN heifers during realimentation was 3.0% higher ($P < 0.05$) than the diet of control animals. Except for ether extract, there were no differences ($P > 0.05$) in the apparent digestibility of dietary nutrients by heifers when evaluating the average of the periods (Table 4).

Table 4. Apparent digestibility of nutrients in the diet of post-weaned heifers under no restriction (control) or receiving compensatory nutrition (CN) on tropical pasture while supplemented with concentrate in periods of restriction and realimentation and the average of periods. SDM: Standard deviation of the mean. Means in the same row and in the same period, followed by different letters, differ from each other according to the F test ($\alpha = 5\%$). DM: Dry matter; OM: organic matter; CP: crude protein; EE: ether extract; NDF: neutral detergent fiber; NFC: non-fibrous carbohydrates; TDN: total digestible nutrients.

	Restriction			Realimentation			Average of periods		
	Control	CN	SDM ¹	Control	CN	SDM ¹	Control	CN	SDM ¹
DM, %	63.07	62.56	1.884	64.48 ^a	59.59 ^b	2.419	63.77	61.08	8.240
OM, %	63.79	63.52	1.782	65.17 ^a	59.99 ^b	2.315	64.48	61.75	7.637
CP, %	65.95 ^a	63.04 ^b	1.870	57.35 ^a	53.66 ^b	3.164	61.65	58.35	7.920
EE, %	58.39 ^a	55.61 ^b	1.938	57.63 ^a	53.92 ^b	3.068	58.01 ^a	54.77 ^b	5.131
NDF, %	58.48 ^b	63.16 ^a	2.919	61.92 ^a	53.99 ^b	2.144	60.20	58.57	6.176
NFC, %	65.96 ^a	57.66 ^b	6.737	70.06 ^a	65.64 ^b	3.596	68.01	61.65	19.968
TDN, %	67.31 ^a	64.96 ^b	1.918	65.08 ^b	67.04 ^a	1.652	66.20	66.00	8.791

During the first restriction (Period 1), there was no difference ($P > 0.05$) in the performance between CN and control heifers. Despite similar body weight ($P > 0.05$) to the control, CN heifers exhibited greater ($P < 0.05$) total weight gain (in all units expressed) and feed efficiency than the control animals in the first realimentation (Period 2). In the second restriction (Period 3), there was a 44.4% reduction ($P < 0.05$) in final weight gain (kg) and a worsening ($P < 0.05$) (+46.9%) in the feed conversion ratio of CN heifers compared to control animals. However, in the second realimentation (Period 4), there was an increase in the average daily gain (ADG) (+23.9%) and feed efficiency (+25%) of CN heifers compared to control animals (Table 5).

When evaluating the performance of the entire period (238 d), compensatory nutrition did not influence ($P > 0.05$) ADG or total weight gain, with mean values of 726.8 g d⁻¹, 162.8 kg, 737.9 g d⁻¹, and 165.3 kg for control and CN heifers, respectively. Compensatory gains of 129% and 125% were observed from the 1st restriction to the 1st realimentation and from the 2nd restriction to the 2nd realimentation, respectively. In the total experiment period, compensatory gain was 136% (Table 6).

Table 5. Performance of post-weaned heifers under no restriction (control) or receiving compensatory nutrition (CN) on tropical pasture while supplemented with concentrate in periods of restriction and realimentation. SDM: Standard deviation of the mean. ¹Percentage of body weight. Means in the same row and in the same period, followed by different letters, differ from each other according to the F test ($\alpha = 5\%$). BW: Body weight; TWG: total weight gain; ADG: average daily gain; FC: feed conversion; FE: feed efficiency.

	Period 1 (Restriction)			Period 2 (Realimentation)			Period 3 (Restriction)			Period 4 (Realimentation)		
	Control	CN	SDM	Control	CN	SDM	Control	CN	SDM	Control	CN	SDM
Initial BW, kg	187.5	187.4	13.496	229.6	223.0	15.388	278.3	280.2	17.314	302.4	293.1	20.843
Final BW, kg	229.6	223.0	15.388	278.3	280.2	17.593	302.4	293.1	20.843	350.3	352.7	21.090
TWG, kg	42.1	35.6	8.664	48.7 ^b	57.2 ^a	4.818	24.1 ^a	13.4 ^b	7.566	48.1 ^b	59.6 ^a	7.916
TWG, g kg ⁻¹ BW	3.6	3.1	0.744	3.4 ^b	4.1 ^a	0.334	1.5 ^a	0.9 ^b	0.424	2.6 ^b	3.3 ^a	0.469
TWG, g 100 kg ⁻¹ BW	360.7	310.1	74.459	342.0 ^b	407.5 ^a	33.353	147.8 ^a	91.1 ^b	40.087	263.9 ^b	330.4 ^a	47.247
ADG, g d ⁻¹	751.8	635.7	154.706	869.6 ^b	1021.4 ^a	86.041	431.2 ^a	263.9 ^b	118.271	858.6 ^b	1063.7 ^a	141.289
FC, kg kg ⁻¹	5.5	6.0	1.420	5.5 ^a	4.6 ^b	0.449	16.4 ^b	24.1 ^a	5.443	8.5 ^a	6.8 ^b	1.247
FE, kg kg ⁻¹	0.19	0.17	0.043	0.18 ^b	0.22 ^a	0.018	0.06	0.05	0.009	0.12 ^b	0.15 ^a	0.022

Table 6. Compensatory gain (CG) of post-weaned heifers under no restriction (control) or receiving compensatory nutrition (CN) on tropical pasture while supplemented with concentrate in periods of restriction, realimentation, and the average of periods. ¹ CG (%) = 100 × (A - B)/A, when CG = 100%, the value lost during restriction has been fully recovered during realimentation; A is difference between the final body weight (FBW) of animals under CN and control animals at the end of the restriction period; B is difference between the FBW of animals under CN and control animals at the end of the realimentation period. BW: Body weight.

	1st restriction to 1st realimentation		2nd restriction to 2nd realimentation		1st restriction to 2nd realimentation	
	Period 1 (Restriction)	Period 2 (Realimentation)	Period 3 (Restriction)	Period 4 (Realimentation)	Period 1 (Restriction)	Period 4 (Realimentation)
Control final BW, kg	229.60	278.30	302.45	350.30	229.60	350.30
CN final BW, kg	223.00	280.20	293.10	352.67	223.00	352.67
Compensatory gain, % ¹		129		125		136

DISCUSSION

During the restriction period, compensatory nutrition (CN) heifers were provided 80% of the concentrate supplement to meet their energy and protein requirements (see lower supplement DM intake), leading to an augmented forage DM intake to fulfill their nutritional needs (Santos et al., 2022). The diet, characterized by a higher proportion of forage and a lower proportion of concentrate supplement, resulted in reduced intakes of crude protein (CP), non-fibrous carbohydrates (NFC), total digestible nutrients (TDN), and metabolizable energy

(ME) by CN heifers (Dong et al., 2019). The diminished DM intake from the concentrate supplement also elucidates the lower apparent digestibility of CP and NFC and TDN content in the diet of CN heifers (Franco et al., 2016). Tropical forages contain carbohydrates and proteins with lower degradability compared to concentrate ingredients (Pereira et al., 2010; Das et al., 2015). This explains the reduction in intake and digestibility of these fractions (CP and NFC) when the proportion of concentrate ingredients in the diet decreased. The heightened neutral detergent fiber (NDF) digestibility observed during the restriction period by CN heifers is possibly attributed to the greater intake of this fraction and the quality of available forage (Ciriaco et al., 2022). In this context, Imaz et al. (2022) reported that grazing cattle, under restricted diets, exhibited higher lipids (indicating adipose mobilization) and acetate (indicating a diet richer in NDF) in their metabolic profile.

Conversely, during the realimentation period, CN heifers received 120% of the concentrate supplement to fulfill their energy and protein needs, resulting in an increased DM intake from the concentrate supplement. The greater supply of DM from the supplement possibly explains the reduction in DM intake from forage observed in CN heifers (Machado et al., 2019). It is likely that, during the realimentation phase, CN heifers experienced a substitution effect on DM intake, increasing the intake of concentrate DM (substitution effect on NFC) while decreasing forage intake (substitution effect on NDF intake) (Lins et al., 2022). Furthermore, there was a reduction in the digestibility of DM and all its fractions (OM, CP, ether extract, NDF, and NFC) from the diet of CN heifers, a phenomenon attributed to the reduction in digesta residence time in the rumen-reticulum (i.e., increased passage rate) due to the elevated intake of supplement DM (Sugg et al., 2021).

Possibly due to the high quality and availability of pasture (Delevatti et al., 2019), we did not observe an effect of the 1st restriction (Period 1) on the performance of CN heifers. However, during the 2nd restriction (Period 3), the CN heifers consistently exhibited lower performance than the control animals. This can be attributed to the low quality and availability of pasture (Zanine et al., 2018), and the dry season, imposing a dual penalty on CN heifers. In the realimentation periods (Periods 2 and 4), CN heifers displayed greater average daily gain and feed efficiency, mainly due to the consumption of more digestible nutrients (during realimentation, CN animals received 120% of the concentrate supplement to meet their energy and protein needs). Thus, although there was no difference in final body weight in the experimental periods, there were complete compensatory gains (as seen in the greater average daily gain in CN heifers) in the realimentation periods. Compensation is considered complete when the animal successfully restores, through more pronounced growth, the lower performance that occurred during the period of nutritional stress. Moreover, Miszura et al. (2021) suggested that moderate compensatory nutrition did not influence the age of entry into puberty of zebu heifers, reinforcing this strategy as viable for herds in tropical zones.

It is important to note that the final body weight of CN animals did not differ from that of control animals, and compensatory gain was complete (136%) within the 238 d evaluated. Keady et al. (2021) also found no effect of compensatory nutrition (99 d restriction and 200 d realimentation) on the intake or performance of taurine steers. It is possible that the similarity in total DM intake (Roch et al., 2005), low intensity of restriction (80%) with subsequent realimentation (120%) (Roche et al., 2015), and the age of the heifers (12 mo) (Hennessy and Morris, 2003) allowed full recovery from performance losses observed in the restriction period. Zhang et al. (2018) suggested hepatic mitochondrial biogenesis as an adaptive mechanism during moderate energy restriction and realimentation to recover ruminant performance.

CONCLUSIONS

Compensatory nutrition for dairy heifers, undergoing alternating periods of energy/protein restriction and subsequent realimentation during pre-puberty, does not impact the intake or digestibility of dietary nutrients. Instead, it facilitates complete compensatory weight gain, fully recovering body weight losses incurred during restriction periods. Therefore, we recommend implementing a management strategy involving an 80% restriction of crude protein and total digestible nutrient requirements, followed by a 120% realimentation phase for these nutrients, lasting approximately 60 d. This approach proves to be an effective management tool for post-weaned Guzoldo heifers on tropical pasture receiving a concentrate supplement at 2.5% of their body weight.

Author contribution

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

Acknowledgements

This study was funded by the Coordination for the Improvement of Higher Education Personnel (CAPES); National Council for Scientific and Technological Development (CNPq) and the “Fundação de Amparo à Pesquisa do Estado da Bahia (FAPESB)”.

References

- AOAC. 1990. Official methods of analysis. 15th ed. Association of Official Analytical Chemistry (AOAC), Arlington, Virginia, USA.
- Ashfield, A., Wallace, M., Mcgee, M., Crosson, P. 2014. Bioeconomic modelling of compensatory growth for grass-based dairy calf-to-beef production systems. *Journal of Agricultural Science* 152:805-816. doi:10.1017/S0021859613000531.
- Barroso, D.S., da Silva, F.F., Azevedo, J.A.G., de Carvalho, G.G.P., Trindade Junior, G., Silva, J.W., et al. 2025. Performance, carcass traits, and meat attributes of steers finished on tropical pasture under increasing supplementation levels. *Chilean Journal of Agricultural Research* 85:161-169. doi:10.4067/S0718-58392025000200161.
- Busanello, M., Sousa, D.G., Mendonça, F.A.C., Daley, V.L., Almeida, R., Bittar, C.M.M., et al. 2021. Feed intake of growing dairy heifers raised under tropical conditions: A model evaluation using meta-analysis. *Animals* 11:113181. doi:10.3390/ani11113181.
- Castro, M.M.D., Devries, T.J., Machado, A.F., Ferreira, M.M., Renno, L.N., Marcondes, M.I. 2023. Metabolic responses and performance of Holstein × Gyr heifers grazing *Brachiaria decumbens* supplemented with varied crude protein levels. *PLOS ONE* 18:0289747. doi:10.1371/journal.pone.0289747.
- Ciriaco, F.M., Henry, D.D., Schulmeister, T.M., Sanford, C.D., Canal, L.B., Fontes, P.L.P., et al. 2022. Intake, ruminal fermentation parameters, and apparent total-tract digestibility by beef steers consuming Pensacola bahiagrass hay treated with calcium oxide. *Journal of Animal Science* 100:skab366. doi:10.1093/jas/skab366.
- Das, L.K., Kundu, S.S., Kumar, D., Datt, C. 2015. Fractionation of carbohydrate and protein content of some forage feeds of ruminants for nutritive evaluation. *Veterinary World* 8:197-202. doi:10.14202/vetworld.2015.197-202.
- Detmann, E., Souza, M.A., Valadares Filho, S.C., Queiroz, A.C., Berchielli, T.T., Saliba, E.O.S., et al. 2012. Métodos para análise de alimentos. In Instituto Nacional de Ciência e Tecnologia-Ciência Animal (ed.) Suprema Gráfica e Editora, Visconde do Rio Branco, Minas Gerais, Brasil.
- Delevatti, L.M., Romanzini, E.P., Koscheck, J.F.W., Araújo, T.L., Renesto, D.M., Ferrari, A.C., et al. 2019. Forage management intensification and supplementation strategy: Intake and metabolic parameters on beef cattle production. *Animal Feed Science and Technology* 247:74-82. doi:10.1016/j.anifeedsci.2018.11.004.
- Dong, L., Li, B., Diao, Q. 2019. Effects of dietary forage proportion on feed intake, growth performance, nutrient digestibility, and enteric methane emissions of Holstein heifers at various growth stages. *Animals* 9:725. doi:10.3390/ani9100725.
- Franco, M.O., Detmann, E., Valadares Filho, S.C., Rufino, L.M.A., Barbosa, M.M., Lopes, A.R. 2016. Intake, digestibility, and rumen and metabolic characteristics of cattle fed low-quality tropical forage and supplemented with nitrogen and different levels of starch. *Asian-Australasian Journal of Animal Sciences* 30:0629. doi:10.5713/ajas.16.0629.
- Hennessy, D.W., Morris, S.G. 2003. Effect of a preweaning growth restriction on the subsequent growth and meat quality of yearling steers and heifers. *Australian Journal of Experimental Agriculture* 43:335-341. doi:10.1071/EA02072.
- Henley, P.A., Ireland, F.A., Canisso, I.F., Edwards, J.L., Shike, D.W. 2021 Effects of management system on beef heifer growth and reproductive performance. *Animal Science* 5:txaa209. doi:10.1093/tas/txaa209.
- Imaz, J.A., García, S., González, L.A. 2022. The metabolomics profile of growth rate in grazing beef cattle. *Scientific Reports* 12:2554. doi:10.1038/s41598-022-06592-y.
- Keady, S.M., Keane, M.G., Wylie, A.R., Riordan, E.G.O. 2021. Effect of dietary restriction and compensatory growth on performance, carcass characteristics, and metabolic hormone concentrations in Angus and Belgian Blue steers. *Animal* 15:100215. doi:10.1016/j.animal.2021.100215.
- Lawrence, T.L.J., Fowler, V.R., Novakofski, J.E. 2012. Growth of farm animals. 3rd ed. CABI, Tarxien, Malta.
- Licitra, G., Hernandez, T.M., Van Soest, P.J. 1996. Standardization of procedures for nitrogen fractionation of ruminant feeds. *Animal Feed Science and Technology* 57:347-358. doi:10.1016/0377-8401(95)00837-3.
- Lins, T.O.J.D.A., Silva, R.R., Mendes, F.B.L., Silva, F.F., Bastos, E.S., Paixão, T.R., et al. 2022. Feeding behavior of post-weaned crossbred steers supplemented in the dry season of the year. *Tropical Animal Health and Production* 54:203. doi:10.1007/s11250-022-03209-4.
- Machado, W.S., Brandao, V.L.N., Morais, V.C.L., Detman, E., Rotta, P.P., Marcondes, M.I. 2019. Supplementation strategies affect the feed intake and performance of grazing replacement heifers. *PLOS ONE* 14:0221651. doi:10.1371/journal.pone.0221651.

- Miszura, A.A., Ferraz, M.V.C., Cardoso, R.C., Polizel, D.M., Oliveira, G.B., Gobato, L.G.M., et al. 2021. Implications of growth rates and compensatory growth on puberty attainment in Nellore heifers. *Domestic Animal Endocrinology* 74:106526. doi:10.1016/j.domaniend.2020.106526.
- Monari-DeLucia, A., Alava, E.M., Hersom Pas, M.J., Thrift, T.A., Yelich, J.V. 2016. Deferred rate of gain effects on growth, body composition, and concomitant blood metabolites in yearling Angus and Brangus heifers. *Professional Animal Scientist* 32:647-657. doi:10.15232/pas.2015-01484.
- Nieman, C.C., Madzonga, Z., Young-Kenworthy, A.N., Coffey, K.P. 2023. Intake, digestibility, ruminal fermentation, and in situ disappearance of Bermudagrass hay by lactating beef cows offered corn or hominy feed as supplements at two different rates. *Journal Animals* 13:1845. doi:10.3390/ani13111845.
- NRC. 2016. Nutrient requirements of beef cattle. 8th ed. National Research Council (NRC), National Academy Press, Washington, D.C., USA.
- Pereira, E.S., Pimentel, P.G., Duarte, L.S., Mizubuti, I.Y., Araújo, G.L., Carneiro, M.S.S., et al. 2010. Determinação das frações proteicas e de carboidratos e estimativa do valor energético de forrageiras e subprodutos da agroindústria produzidos no Nordeste Brasileiro. *Semina: Ciências Agrárias* 31:1079-1094. doi:10.5433/1679-0359.2010v31n4p1079.
- Roch, T., Jurie, C., Pradel, P., Cassar-Malek, I., Jailler, R., Picard, B., et al. 2005. Effects of hay quality on intake, growth path, body composition and muscle characteristics of Salers heifers. *Animal Research* 54:241-257. doi:10.1051/animres:2005022.
- Roche, J.R., Dennis, N.A., Macdonald, K.A., Phyn, C.V.C., Amer, P.R., White, R.R., et al. 2015. Growth targets and rearing strategies for replacement heifers in pasture-based systems: A review. *Animal Production Science* 55:902-915. doi:10.1071/AN14880.
- Santos, A.R.M., Cabral, C.H.A., Cabral, C.E.A., Barros, L.V., Pires, D.F., Rosa, A.R., et al. 2022. Energy supplementation as strategy of pasture management. *Animal Acta Sciences* 44:55761. doi:10.4025/actascianimsci.v44i1.55761.
- Sugg, J.D., Sarturi, J.O., Henry, D.D., Ciriaco, F.M., West, C.P., Ballou, A.M., et al. 2021. Ruminal degradation kinetics, intake, digestibility, and feeding behavior of beef steers offered annual or perennial grass-hay with or without supplementation. *Journal of Animal Science* 99:168. doi:10.1093/jas/skab168.
- Van Soest, P.J. 1964. Symposium on nutrition and forage and pastures: new chemical procedures for evaluating forages. *Journal of Animal Science* 23:838-845.
- Wilson, P.N., Osbourne, D.F. 1960. Compensatory growth after undernutrition in mammals and birds. *Biological Reviews* 35:324-363.
- Zanine, A.M., Motta, G.P.R., Ferreira, D.J., Souza, A.L., Ribeiro, M.D., Geron, L.J.V., et al. 2018. Milk performance and grazing behaviour of dairy cows in response to pasture allowance. *Animal Production Science* 59:749-756. doi:10.1071/AN17513.
- Zanton, G.I., Heinrichs, A.J. 2005. Meta-analysis to assess effect of prepubertal average daily gain of Holstein heifers on first-lactation production. *Journal of Dairy Science* 88:3860-3867. doi:10.3168/jds.S0022-0302(05)73071-X.
- Zhang, G.M., Zhang, T.T., Jin, Y.H., Liu, J.L., Guo, Y.X., Fan, Y.X., et al. 2018. Effect of caloric restriction and subsequent re-alimentation on oxidative stress in the liver of Hu sheep ram lambs. *Animal Feed Science and Technology* 237:68-77. doi:10.1016/j.anifeedsci.2018.01.009.