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Animal performance and methane emissions in feedlot vs. traditional pastoral systems with concentrate supplementation for Tanzanian Short Horn Zebu and Boran cattle

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The current study examined the effect of concentrate supplementation on beef cattle performance and methane (CH₄) emissions in traditional pastoral systems in Tanzania. The study used summarized data (least square means, SEM, n) from a previous experimental study conducted in Tanzania in 2007–08, as the raw data are not available. The experiment involved 60 Boran and 60 Tanzanian Shorthorn Zebu (TSHZ) cattle, assigned to five dietary treatments for 100 days: grazing alone (GrazC00), grazing with 50% concentrate (GrazC50), and *ad libitum* hay with 60%, 80%, and 100% concentrate supplementation (HayC60, HayC80, and HayC100, respectively). The concentrate levels (50%, 60%, 80%, and 100%) were determined relative to the *ad-libitum* concentrate intake established before the experiment. The experiment measured dry matter intake (DMI) and live weights throughout the experimental periods. The current study calculated average daily weight gain (ADG) and daily CH₄ production (DMP) following the 2019 Refinement to the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines. The estimated CH₄ emissions were then used to calculate emission intensity (EI) relative to weight gain (EI_{WG}, g CH₄/kg WG). Statistical analysis used the lme4 package in R and the lm function to fit ANOVA with breed and treatment main effects and their interaction, with significance set at $p < 0.05$. Results showed that concentrate supplementation increased ADG by 6%–33% and decreased DMP by 3%–35%, regardless of breed. Among treatments, HayC100 had the lowest DMP, indicating greater efficiency at higher concentrate levels. In both breeds, EI decreased as concentrate levels increased from 0% to 100%, with the lowest EI_{WG} observed in the HayC100 treatment (from 396 at GrazC00 to 87 g CH₄/kg WG at HayC100). The reduction in EI_{WG} was consistent across both breeds, showing that the supplementation effect was similar regardless of breed differences. Overall, concentrate supplementation improved cattle performance and reduced DMP,

due to decreased CH_4 conversion factor (Y_m), and lower EIs. These findings suggest that concentrate supplementation could be an effective strategy for enhancing beef production efficiency and reducing environmental impact in Tanzania.

KEYWORDS

concentrate supplementation, enteric methane, emission intensity, Boran, Tanzanian Shorthorn Zebu

Introduction

Cattle production plays a crucial role in Tanzania's agricultural sector, contributing to poverty reduction and food security (Suleiman, 2018). It is an integral component of mixed-crop livestock farming systems, directly or indirectly enhancing household income and food security (Mdoe et al., 2021). However, the growing domestic demand for beef poses a challenge due to rapid population growth and increased incomes, which have led to higher *per capita* consumption (Desiere et al., 2018; Kibona et al., 2022).

Traditional pastoral livestock production systems dominate the sector, accounting for 94% of beef cattle production. However, productivity is suboptimal due to high mortality rates, disease prevalence, poor reproductive performance, and forage scarcity (MLFD, 2015; Michael et al., 2018). The productivity losses attributed to forage scarcity can be significant. Lyatuu et al. (2023) indicated that limited access to forage, both in quantity and quality, can reduce cattle weight gain by up to 30%, aggravating the challenges faced by farmers. Moreover, forage scarcity during the dry season exacerbates these challenges, leading to cyclic weight fluctuations and increasing both feed resource requirements and the time to reach slaughter weight (Kanuya et al., 2006). The primary beef cattle breeds in Tanzania include the Tanzania Shorthorn Zebu (TSHZ), with a mature body weight ranging from 200 to 350 kg, and the Boran breed, with a larger body weight of 500–800 kg (MLF, 2018). Despite their adaptability to local conditions, these breeds exhibit slower growth rates compared to exotic breeds when raised under traditional grazing systems (Msalya et al., 2017). To address these challenges, strategies such as improved nutrition are being explored.

One promising approach to enhance cattle meat production is concentrate supplementation (Selemani et al., 2015). Concentrates commonly used in Tanzanian systems are formulated from locally available ingredients such as maize bran, cottonseed cake, sunflower seed cake, and fish meal. These provide energy and protein diversity to complement low-quality forages, thereby improving the nutritional value of grazing cattle diets and promoting growth (Steinfeld et al., 2006; Mwangi et al., 2019). The average daily gain of feedlot-finished animals in Tanzania was nearly threefold higher than that of grazed ones (Mushi, 2020). However, while feedlot systems are known to improve growth, the optimal levels of concentrate

supplementation within feedlot conditions, and in comparison with grazing, have not been established (Selemani et al., 2015; Asimwe et al., 2016; Mushi, 2020). Enteric CH_4 emissions from livestock contribute significantly to agricultural greenhouse gas (GHG) emissions in Tanzania. In 2014, enteric CH_4 accounted for 39.7% of agricultural emissions in the country (Mushi et al., 2015; Seif and Kipkirui, 2024). Mitigating enteric CH_4 emissions offers an opportunity for near-term impact reduction, potentially aiding efforts to limit global temperature rise to 1.5 °C (Collins et al., 2018).

Concentrate supplementation also holds the potential for mitigating enteric CH_4 emissions by improving the feed conversion ratio (FCR) and reducing emission intensities (EI = emissions per unit of product) (White et al., 2014). Mitigation strategies implemented in other parts of Africa have shown potential in increasing diet digestibility and reducing enteric CH_4 emissions (Korir et al., 2022). Berhanu et al. (2019) demonstrated that integrating improved forage varieties (*Leucaena leucocephala*, *Moringa stenopetala*, *Sesbania sesban*, *Cajanus cajan*, *Crotalaria juncea*, and *Lablab purpureus*) can reduce enteric CH_4 emissions by up to 25% while simultaneously enhancing livestock productivity. However, there is little data regarding animal productivity improvement and enteric CH_4 mitigation in pastoral cattle systems in Tanzania, particularly through concentrate supplementation.

Therefore, the objective of this study was to investigate whether feedlot and grazing systems, with and without concentrate supplementation, will result in improved animal performance and lower enteric CH_4 emissions per product compared to traditional pastoral systems. By exploring this potential among Tanzanian Short Horn and Boran cattle, this research seeks to contribute to the development of sustainable cattle production systems in Tanzania, while acknowledging that the sustainability of concentrate-based interventions depends on the availability and cost of local feed resources.

Materials and methods

For the estimation of enteric CH_4 emissions and other parameters, we used summarized data (least square means, SEM, n) from a previous experimental study conducted in Tanzania in 2007–08 to calculate derived parameters, maintaining the distribution properties of the original data, as

TABLE 1 Growth performance and diet composition (Boran vs. TSHZ steers, Kongwa Ranch, 2007–2008).

Parameter	Breed	n	Initial LW (kg)	Final LW (kg)	DMI (kg/d)	CP (g/kg DM)	NDF (g/kg DM)	ADF (g/kg DM)	GE (MJ/kg DM)	DE (%)
GrazC00	Boran	12	168 ± 3.1	237 ± 5.0	8.3 ± 0.05	83	578	341	17.5	59.3
	TSHZ	12	98 ± 3.1	154 ± 5.0	7.7 ± 0.05	83	578	341	17.5	59.3
GrazC50	Boran	12	168 ± 3.1	248 ± 5.0	7.7 ± 0.05	97	480	263	18.0	65.8
	TSHZ	12	100 ± 3.1	163 ± 5.0	7.2 ± 0.05	95	491	271	17.9	65.1
HayC60	Boran	12	167 ± 3.1	224 ± 5.0	6.6 ± 0.05	107	397	187	18.8	70.3
	TSHZ	12	95 ± 3.1	149 ± 5.0	5.1 ± 0.05	102	430	212	18.7	68.0
HayC80	Boran	12	168 ± 3.1	245 ± 5.0	6.9 ± 0.05	111	369	167	18.8	72.3
	TSHZ	12	104 ± 3.1	162 ± 5.0	5.6 ± 0.05	114	353	154	18.9	73.4
HayC100	Boran	12	169 ± 3.1	255 ± 5.0	7.5 ± 0.05	118	326	134	18.9	75.4
	TSHZ	12	99 ± 3.1	180 ± 5.0	6.3 ± 0.05	117	331	138	18.9	75.0

GrazC00 = grazing alone as control; GrazC50 grazing + 50% *ad libitum* concentrate intake; HayC60, HayC80, and HayC100 = (*ad libitum* hay + 60, 80, and 100% of the *ad libitum* concentrate intake, respectively). TSHZ, tanzanian short horn zebu; DMI, dry matter intake; FCR, feed conversion ratio; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; GE, gross energy; DE, digestible energy. There were no SE, values for feed parameters since the analysis was conducted on pooled feed samples.

shown in Table 1. Using the least square mean, standard error of mean (SEM), and number of animals, we back-calculated the lower and upper 95% confidence limits (CL) to provide three values for each variable: the mean, lower and upper 95% CL for initial live weight (ILW), final live weight (FLW), and dry matter intake (DMI), assuming the residuals for the original raw data analysis were normally distributed. The minimum, mean, and maximum values were then utilized to derive or compute average daily weight gain (ADG, kg/day), feed conversion ratio (FCR, kg DMI/kg ADG), daily CH₄ production (DMP, g CH₄/day), CH₄e yield (MY, g CH₄/kg DMI), and emission intensity of weight gain (EI_{WG}, g CH₄/kg WG). The analysis results indicate the range of values between breeds, treatments, or their interactions. If the *p*-value shows significance, it was stated that breed, treatments, or their interaction had significant differences in the range of parameters estimated.

The details of the experiment conducted at Kongwa Ranch in Tanzania (S 6° 03.810' and E 36° 27.296' at an altitude of 1,067 m) from mid-November 2007 to March 2008, during the wet season, are described in sections *Animals experimental design*, *Treatment diets*, *Feed intake and animal performance measures* as follows.

Animals experimental design

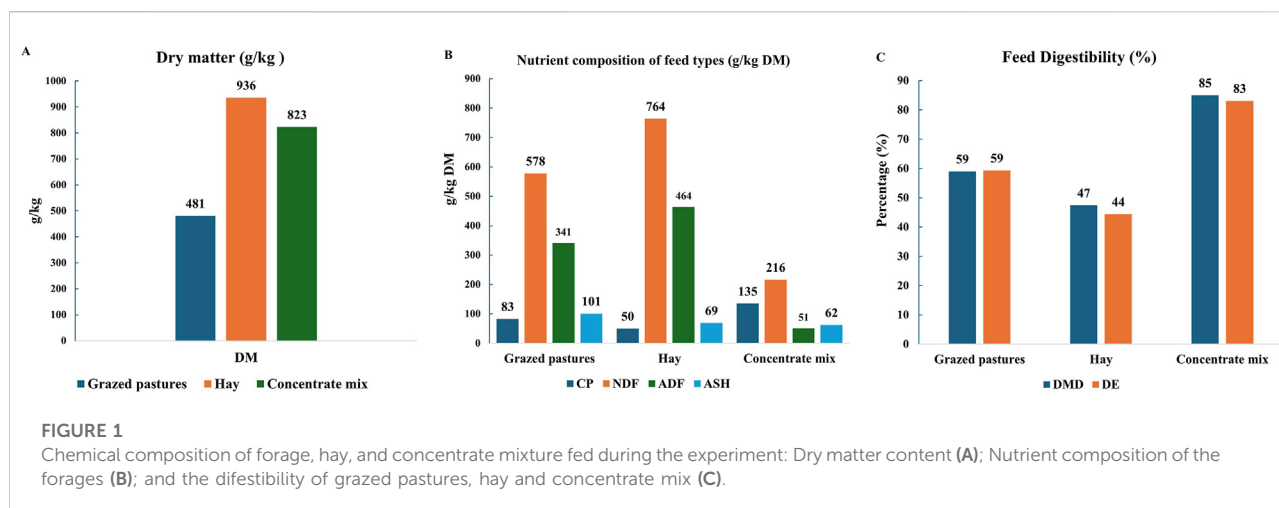
The experiment involved 60 Boran steers purchased from Kongwa Ranch, aged between 1 and 2 years, with an initial average weight of (mean ± SE) 168 ± 1.4 kg. Additionally, 60 Tanzania Short-Horn Zebu (TSHZ) steers were acquired from local auction markets, aged between 1.5 and 2.5 years,

with an initial average live weight (LW) of 99 ± 1.4 kg. The age of the TSHZ steers was estimated based on their dentition, while the age of Boran steers was obtained from ranch records. The animals were blocked by breed and assigned to treatments considering their initial average weight. A preliminary 7-day adaptation period involved mixing all steers and providing common feeding and management. During the last 3 days of this preliminary period, the animals were weighed simultaneously for three consecutive days to determine their average initial LW for allocation to dietary treatments. Before each weighing session, animals were deprived of water for a day, then provided water and weighed individually using a digital scale while walking on a platform. Withdrawing water before weighing helped minimize variation in gut fill and provided more accurate body weight measurements. Four steers with similar initial LW and the same breed were grouped in one pen. Each pen served as an experimental unit for feed intake and feed conversion efficiency, whereas an individual animal was considered as an experimental unit for weight change.

The study used a feedlot structure at Kongwa Ranch, comprising 24 pens measuring 4 × 5 m each. The structure featured partial roofing with iron sheets for shade, feeding and watering troughs, and a small shed (palm-thatched) at the rear end to keep shade during sunny hours.

Treatment diets

The dietary treatments included: grazing with no concentrate as a control (GrazC00); grazing plus 50% *ad libitum* concentrate



intake (GrazC50); 60% *ad libitum* concentrate intake plus *ad libitum* hay (HayC60); 80% *ad libitum* concentrate intake plus *ad libitum* hay (HayC80); and *ad libitum* concentrate intake plus *ad libitum* hay (HayC100). The *ad libitum* feeding allowed for approximately 10%–15% refusal. The 50%, 60% and 80% *ad libitum* concentrate intake were expressed relative to the 100% *ad libitum* concentrate intake. The concentrate dietary levels were designed to identify the point at which additional concentrate no longer resulted in proportional performance gains, thereby balancing productivity with feed cost. Grazing alone was included as a reference treatment representing normal farming practice.

Animals on GrazC50 to HayC100 diets were housed in three pens per diet, with four animals per pen. Steers in GrazC00 were kept outside in a wire-fenced kraal at night, while those in GrazC50 were confined in pens at night for concentrate supplementation. Steers in GrazC50, HayC60, HayC80, and HayC100 diets were kept in separate pens throughout the experimental period.

Following the allocation of animals to their treatments and pens, a 19-day adaptation period was provided for the animals to adjust to the feeds, pens, and experimental procedures. During this period, animals in GrazC00 grazed, those in GrazC50 grazed and received evening concentrate supplementation in their pens, and animals in HayC60, HayC80, and HayC100 diets were provided hay *ad libitum*, with proportional concentrate supplementation given to the GrazC50, HayC60, and HayC80 groups until reaching the HayC100 *ad libitum* intake levels.

Grazing took place on natural grassland allocated for GrazC00 and GrazC50 treatments, with *ad libitum* access during the day. The grazed pastures consisted predominantly of perennial grasses (*Aristida adscensionis* 15.7%, *Dictyostelium Aegyptus* 12.8%, *Cenchrus ciliaris* 11.8%) and legumes (*Macrotyloma uniflorum* 11.4%), with other species contributing smaller proportions (<10%). Overall, grass accounted for ~70% of the botanical composition, with legumes and herbs comprising the remainder.

The concentrate feed was formulated using local ingredients purchased from various suppliers. The recipe included maize meal (380 g/kg DM), cotton-seed cake (130 g/kg DM), molasses (470 g/kg DM), mineral mix (10 g/kg DM), salt (5 g/kg DM), and urea (5 g/kg DM). This combination aimed to achieve a final composition of 125 g of crude-protein (CP) per kg DM. The formulation targeted an average daily gain (ADG) of 1 kg per steer. Once the ingredient quantities were calculated, the dry ingredients were weighed and thoroughly mixed to achieve the desired protein level. All concentrate ingredients were provided in dry form, except molasses, which was mixed with dry ingredients at feeding.

Feed intake and animal performance measures

Feed offered and feed refusals for each pen were measured daily, and the difference was taken as the total amount of feed taken by the four animals in each pen. Feed intake was determined per pen, and the value obtained was divided by the number of animals in the pen to obtain an average intake per animal. Animals were weighed on the 30th day and thereafter every 2 weeks until the end of the fattening trial. Animals were weighed in the morning for three consecutive days before the date of slaughter, and the average weight was taken as the final live weight (FLW). The FLW was used together with ILW to calculate ADG.

Sample preparation

Feed samples were first dried at 50 °C for 2 days in a forced-air oven to prevent nutrient losses and allow storage. The dried samples were ground to pass through a 1-mm mesh screen of a hammer mill (MF 10 basic, IKA, Werke GmbH and CO. KG,

Staufen, Germany). For dry matter determination, subsamples were further dried at 105 °C overnight following the AOAC International (2006) procedures. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analyzed according to Van Soest et al. (1991) using an Ankom200 Fibre Analyzer (Ankom Technology Corp., Fairport, NY). Total nitrogen (N) was determined by combustion using a CHN analyzer (Elementar Vario MAX cube, Elementar, Langenselbold, Germany) following the Dumas method of AOAC International (2006), and crude protein (CP) was calculated as 6.25 *N.

Estimation of feed digestibility

The ADF and N were used to estimate dry matter digestibility (DMD) utilizing the Equation 1 from Oddy et al. (1983).

$$\text{DMD}\% = 83.58 - (0.824 \times \text{ADF}\%) + (2.626 \times \text{N}\%) \quad (1)$$

where, DMD% is dry matter digestibility, % DM; ADF% is acid detergent fibre % DM; N% is nitrogen content in the feed, % DM.

The digestible energy as a proportion of gross energy (DE%) was derived from the estimated DMD using Equation 2, derived from CSIRO (2007).

$$\text{DE}\% = \frac{\text{DMD}(\%) \times 0.172 - 1.707}{0.81 \times \text{GE} \left(\frac{\text{MJ}}{\text{kg DM}} \right)} \times 100 \quad (2)$$

where DE% is digestible energy as a percentage of gross energy intake; DMD is the dry matter digestibility in % estimated in Equation 2; GE is the gross energy content of the diets in MJ per kg DM.

Enteric methane emission

We estimated the daily enteric CH₄ production (DMP) based on the DMI measured during the experiment (Equation 3).

$$\text{DMP} \left(\text{kg} \frac{\text{CH}_4}{\text{day}} \right) = \left(\text{DMI} \left(\frac{\text{kg}}{\text{day}} \right) \times \text{GE} \left(\frac{\text{MJ}}{\text{kg DM}} \right) \times \left(\frac{\text{Ym, \%}}{100} \right) \right) \times \frac{1}{55.65} \quad (3)$$

where DMP represents the daily enteric CH₄ emissions (kg CH₄/day) estimated from measured dry matter intake; DMI is dry matter intake (kg/d) measured during the experimental period. GE is the gross energy content of the diets (MJ/kg DM). Ym is the CH₄ conversion factor, which is the extent to which feed energy is converted to CH₄ (IPCC, 2019). Ym values were estimated using equations interpolated from IPCC (2019) Table 10.12, which relates Ym to feed digestibility and energy content (Figure 2). The factor 55.65 (MJ/kg CH₄) is the energy content of CH₄.

The DMP for each treatment was used to calculate total enteric CH₄ for the duration of the experiment (CH₄ kg/head/experiment) and EI (kg CH₄ per kg WG, EI_{WG}).

Statistical analysis

We used the lme4 package in R and the lm function to fit an ANOVA with Breed and Treatment main effects and their interaction for LW, ADG, DMI, FCR, DMP, EI, and MY. The emmeans function was used to estimate least square means and standard errors and to conduct comparisons between different treatments, adjusted for multiple comparisons using Tukey. The $p < 0.05$ was considered a significant difference in the range of parameters estimated. ANCOVA was conducted to check if the ILW of the two breeds influences ADG.

Results

Chemical composition of feeds and diets

Among the feeds, digestibility followed the order: concentrate > pasture > hay, consistent with CP and fibre content differences (Figure 1). This gradient provided a broad range of diet quality for evaluating CH₄ emissions. Increasing the proportion of concentrate in diets raised CP from ~80 to ~120 g/kg DM and DE from ~59% to ~75%, while fibre content declined markedly (Table 1). This wide nutrient gradient supports testing CH₄ responses to dietary quality shifts.

Animal performance

There were differences in ADG between breeds and among treatments (Table 2). Analysis of covariance (ANCOVA), using initial live weight as a covariate, indicated that ILW was negatively associated with ADG. After adjusting for ILW, breed, and treatment effects, ADG remained significant. The FCR improved with higher concentrate levels, lowest in HayC100 (~8.4 kg DMI/kg ADG).

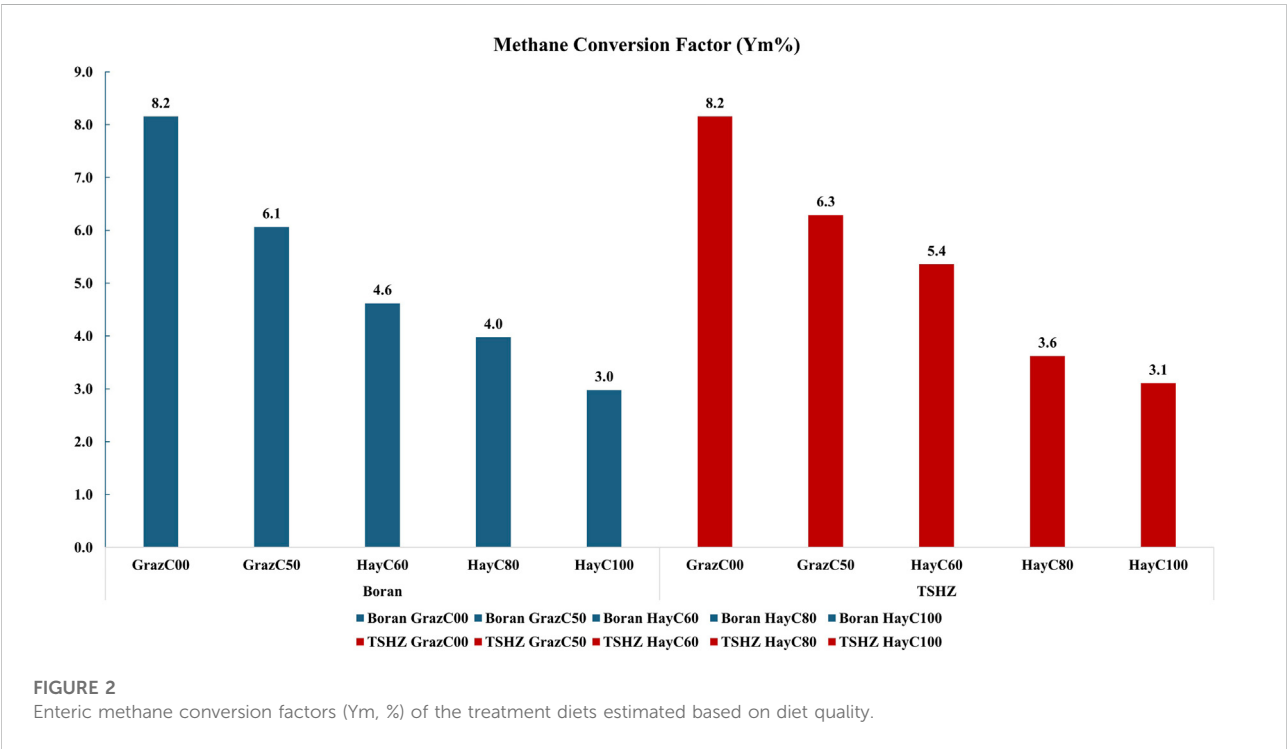
Enteric methane emissions

4. The DMP decreased progressively with concentrate inclusion, falling by 64% in Boran and 67% in TSHZ from GrazC00 to HayC100 (Table 2). Methane conversion factors (Ym) also declined (~60% reduction) as shown in Figure 2. The EI_{WG} followed similar trends, with the lowest in HayC100

TABLE 2 Least square means for the effects of breed and treatment diets on animal performance and enteric methane emissions in indigenous cattle in Tanzania over the 100-day experimental period.

Parameter	N/breed/treatment	Breed	Treatments					Mean	p and SEM		
			GrazC00	GrazC50	HayC60	HayC80	HayC100		B	T	B*T
ADG, g/day	9	Boran	690	800	570	770	860	738	<0.05	<0.05	Ns
		TSHZ	560	630	540	580	810	624	16.8	26.6	37.6
		Mean	625 ^{bc}	715 ^b	555 ^c	675 ^b	835 ^a				
FCR*, kg DMI/kg ADG	27	Boran	-	-	12.0 ^p	9.1 ^{qrs}	8.9 ^{qrst}	10.0	<0.05	<0.05	<0.05
		TSHZ	-	-	9.8 ^{qr}	10.0 ^q	7.9 st	9.3	0.196	0.24	0.34
		Mean	-	-	10.9 ^a	9.6 ^b	8.4 ^c				
DMP (g CH ₄ /day)	3	Boran	213 ^p	151 ^r	102 ^s	93 ^t	76 ^u	127	<0.05	<0.05	<0.05
		TSHZ	198 ^q	146 ^r	92 ^t	69 ^v	66 ^v	114	0.46	0.73	1.04
		Mean	206 ^a	148 ^b	97 ^c	81 ^d	71 ^e				
EI _{WG} (g CH ₄ /kg WG)	27	Boran	401	250	187	123.0	90	205	Ns	<0.05	Ns
		TSHZ	391	265	177	122.9	84	208	3.7	5.9	8.3
		Mean	396 ^a	257 ^b	182 ^c	123 ^d	87 ^e				

LS, Means with different superscripts differ ($p < 0.05$); a-e for treatment effect; p-u for B*T effect; p-value: the probability of values; SEM: standard error of the mean; GrazC00: grazing alone as control; GrazC50: grazing +50% *ad libitum* concentrate intake; HayC60, HayC80, and HayC100: *ad libitum* hay+60,80% and 100% of the *ad libitum* concentrate intake, respectively; Average daily live weight gains in grams; DMI: dry matter intake; FCR: feed conversion ratio. DMP: daily methane production; EI_{WG} emission intensity per weight gain. * FCR was not analyzed for pasture treatments as intake was indirectly derived from weight gain.



(~87–90 g CH₄/kg WG). Breed effects were minor and generally non-significant.

Discussion

Animal feed and performance

Among the diets, the concentrate mix contained the highest CP levels, primarily due to the inclusion of cottonseed cake and urea, both rich in CP. Increasing the proportion of this concentrate mix in the hay- or pasture-based diets improved overall nutrient density, as reflected in the HayC100 treatment, which provided 117–118 g CP/kg DM. These values align with the recommended CP range for fattening bulls (105–145 g CP/kg DM), reported by Menezes et al. (2019) and Costa-Roura et al. (2020). The HayC80 HayC60 diets for Boran cattle also met this range, supporting their intermediate growth performance relative to HayC100.

The highest performance observed for bulls on the HayC100 diet, or ad-libitum concentrate intake, is consistent with findings of Makarechian et al. (1995), who reported that ad-libitum concentrate showed higher ADG (1.8 kg/day) compared to those on restricted concentrate diets (1.3 kg/day) in weaned bulls in a study in Canada. The current study also demonstrated that DMI increased as the concentrate level in a hay diet was increased. Similarly, the current study demonstrated that DMI increased as the concentrate level in hay diets increased, consistent with Moletta et al. (2014), who reported a 14% increase in DMI when the concentrate level increased from 0.8% to 1.4% of live weight.

Although the HayC60 diet contained more concentrate than the GrazC50 diet, animal performance (WG and ADG) was higher in the GrazC50 diet. Although HayC60 had a higher dietary digestibility (DE) than GrazC50, animal performance was higher in GrazC50, suggesting factors beyond DE, such as voluntary intake or differences in nutrient availability from grazed forage, may have influenced weight gains. This is consistent with the findings of Davis et al. (2014), who reported that digestibility accounts for only 35% of the variation in WG.

Comparisons between breeds revealed that Boran cattle exhibited higher ADG across treatments. However, when accounting for ILW as a covariate, part of these differences can be explained by body size, as Boran cattle started the trial heavier than TSHZ. Importantly, a significant breed effect persisted even after this adjustment, suggesting that Boran cattle possess intrinsic growth or feed efficiency advantages beyond differences in starting weight. This nuance helps reconcile our findings with Retallick et al. (2017), who reported breed differences in feed efficiency indices, indicating both efficiency and size contribute to performance differences.

Similarly, Salum et al. (2024) observed higher growth rates in Boran cattle than TSHZ, supporting our conclusion that diet composition (energy/protein density and digestibility) interacts with breed-specific growth potential to drive performance outcomes.

Enteric methane emissions

The present study found that DMP was highest in cattle on GrazC00, whereas concentrate supplementation resulted in reduced enteric CH₄ emissions. This difference is likely driven by the lower Y_m and feed digestibility associated with concentrate supplementation. Pedreira et al. (2013) likewise reported a 33% reduction in Y_m with increased grain supplementation, corroborating the trends observed in the present finding.

In the current study, Y_m values were obtained using IPCC equations rather than being directly measured. While increasing the concentrate ratio led to higher feed intake, it did not increase DMP, contrary to the findings of Jiao et al. (2014) and van Wyngaard et al. (2018). This highlights the critical role of Y_m values in influencing enteric CH₄ emissions, as emphasized by Beauchemin and McGinn (2006). The current study supports their conclusion that variations in Y_m have a greater impact on enteric CH₄ emissions than feed intake alone. It is important to note that Y_m values were not measured but derived using IPCC equations.

Furthermore, considering factors beyond the forage-to-concentrate ratio, such as feed digestibility and supplement type, is crucial (Jonker et al., 2015). Beauchemin and McGinn (2006) demonstrated that corn-based supplements produced lower CH₄ emissions compared to barley-based supplements. However, applying this approach in Tanzania may be challenging, as cattle are supplemented with the same concentrate mix, making it more relevant to focus on optimizing the forage-to-concentrate ratio rather than altering concentrate composition.

The magnitude of enteric CH₄ reduction in this study was substantially higher than that reported by Huhtanen and Huuskonen (2020), who reported only a 4% reduction in EI between diets with 70% and 30% concentrate supplementation. This difference likely stems from baseline diet quality. The Huhtanen and Huuskonen (2020) study involved diets already optimized for lower emissions, hence the additional reduction from increasing concentrate levels would be smaller (Muetzel et al., 2024). Their control diet (grass silage) had higher digestibility than the grazed pasture in this study, narrowing the forage–concentrate gap. By contrast, the present study's forage-only diet (GrazC00) had low digestibility, magnifying the impact of concentrate supplementation on enteric CH₄ mitigation. These findings underscore the originality of this work, conducted under extensive Tanzanian conditions that

differ markedly from the temperate systems in most published literature.

Breed differences in DMP were also observed, with Boran cattle producing more enteric CH₄ than TSHZ. This is consistent with their higher DMI, linked to larger body size (Stakelum and Connolly, 1987; Walker et al., 2015). Importantly, Y_m value was diet-based and not adjusted for breed, so potential enteric CH₄ yield differences attributable to breed physiology may have been underestimated. Despite Boran cattle being younger (1–2 years old) than TSHZ cattle (1.5–2.5 years), their greater frame size resulted in higher intake and emissions (MLF, 2018).

A limitation of this study is that, while higher concentrate levels effectively improved animal performance and reduced emission intensity, we did not assess the economic feasibility of different supplementation levels. Future work should include cost-benefit analyses to determine the most practical supplementation strategies for producers.

Conclusion

Finishing cattle on pasture with concentrate supplementation proved to be a viable strategy when high-quality pasture is available.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was approved by Tanzania Livestock Research Institute. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

AW: Data collection, Data cleaning, Formal Analysis, Writing – original draft. EG: Methodology, Formal Analysis, Writing – original draft. MW: Conceptualization, Methodology, Fund acquisition, writing – review and editing. GL: Conceptualization. JP: Formal Analysis. CA: Methodology, visualization, writing – review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

- AOAC International (2006). *Official methods of analysis*. 18th ed. Arlington, VA, USA: AOAC International.
- Asimwe, L., Kimambo, A., Laswai, G., Mtenga, L., Weisbjerg, M. R., and Madsen, J. (2016). Economics of finishing Tanzania shorthorn zebu cattle in feedlot and optimum finishing period. *Livest. Res. Rural. Dev.* 28, 1–11.
- Beauchemin, K. A., and McGinn, S. M. (2006). Enteric methane emissions from growing beef cattle as affected by diet and level of intake. *Can. J. Anim. Sci.* 86, 401–408. doi:10.4141/a06-021
- Berhanu, Y., Olav, L., Nurfeta, A., Angassa, A., and Aune, J. B. (2019). Methane emissions from ruminant livestock in Ethiopia: promising forage species to reduce CH₄ emissions. *Agriculture* 9, 130. doi:10.3390/agriculture9060130
- Collins, W. J., Webber, C. P., Cox, P. M., Huntingford, C., Lowe, J., Sitch, S., et al. (2018). Increased importance of methane reduction for a 1.5 degree target. *Environ. Res. Lett.* 13, 054003. doi:10.1088/1748-9326/aab89c
- Costa-Roura, S., Balcells, J., de La Fuente, G., Mora-Gil, J., Llanes, N., and Villalba, D. (2020). Effects of protein restriction on performance, ruminal fermentation and microbial community in holstein bulls fed high-concentrate diets. *Animal Feed Sci. Technol.* 264, 114479. doi:10.1016/j.anifeeds.2020.114479
- CSIRO (2007). *Nutrient requirements of domesticated ruminants*. Collingwood, VIC, Australia: CSIRO Publishing.
- Davis, M., Freetly, H., Kuehn, L., and Wells, J. (2014). Influence of dry matter intake, dry matter digestibility, and feeding behavior on body weight gain of beef steers. *J. Animal Sci.* 92, 3018–3025. doi:10.2527/jas.2013-6518
- Desiere, S., Hung, Y., Verbeke, W., and D'Haese, M. (2018). Assessing current and future meat and fish consumption in sub-sahara Africa: learnings from FAO food balance sheets and LSMS household survey data. *Glob. Food Secur.* 16, 116–126. doi:10.1016/j.gfs.2017.12.004
- Huhtanen, P., and Huuskonen, A. (2020). Modelling effects of carcass weight, dietary concentrate and protein levels on the CH₄ emission, N and P excretion of dairy bulls. *Livestock Sci.* 232, 103896. doi:10.1016/j.livsci.2019.103896
- IPCC (2019). "Emissions from livestock and manure management," in *2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories, volume 4: agriculture, forestry and other land use*. Editors Buendia, E. C., Tanabe, K., Kranjc, A., Jamsranjav, B., Fukuda, M., and Ngarize, S. (Geneva, Switzerland: IPCC).
- Jiao, H., Dale, A., Carson, A., Murray, S., Gordon, A., and Ferris, C. (2014). Effect of concentrate feed level on methane emissions from grazing dairy cows. *J. Dairy Sci.* 97, 7043–7053. doi:10.3168/jds.2014-7979
- Jonker, A., Muetzel, S., Molano, G., and Pacheco, D. (2016). Effect of fresh pasture forage quality, feeding level and supplementation on methane emissions from growing beef cattle. *Anim. Prod. Sci.* 56, 1714–1721. doi:10.1071/an15022
- Kanuya, N., Matiko, M., Nkya, R., Bittegeko, S., Mgasa, M., Reksen, O., et al. (2006). Seasonal changes in nutritional status and reproductive performance of zebu cows kept under a traditional agro-pastoral system in Tanzania. *Trop. Anim. Health Prod.* 38, 511–519. doi:10.1007/s11250-006-4419-z
- Kibona, C. A., Yuejie, Z., and Tian, L. (2022). Factors that influence beef meat production in Tanzania. A Cobb-douglas production function estimation approach. *PLoS One* 17, e0272812. doi:10.1371/journal.pone.0272812
- Korir, D., Eckard, R., Goopy, J., Arndt, C., Merbold, L., and Marquardt, S. (2022). Effects of replacing brachiaria hay with either Desmodium intortum or dairy concentrate on animal performance and enteric methane emissions of low-yielding dairy cows. *Front. Animal Sci.* 3, 963323. doi:10.3389/fanim.2022.963323
- Lyatuu, E. T., Komwihangilo, D., Msuta, G., Kelya, N., Okeyo, M., Ojango, J., et al. (2023). Unlocking total factor productivity of smallholder dairy farmers in Tanzania. *Tanzan. J. Agric. Sci.* 22, 338–345.
- Makarechian, M., Arthur, P., Liu, M., and Okine, E. (1995). The effect of level of concentrate in feedlot diets on growth, health and carcass characteristics of bulls. *J. Appl. Animal Res.* 7, 49–62. doi:10.1080/09712119.1995.9706050
- Mdoe, N. S. Y., Mlay, G. I., Boniface, G., Isinika, A. C., and Magomba, C. (2021). Livestock, crop commercialisation and poverty reduction among rural households in the Singida region, Tanzania. *APRA, Work. Pap.* 65, *Brighton Future Agric. Consort.* doi:10.19088/APRA.2021.024
- Menezes, A. C. B., Valadares Filho, S. C., Pacheco, M. V., Pucetti, P., Silva, B. C., Zanetti, D., et al. (2019). Oscillating and static dietary crude protein supply. I. Impacts on intake, digestibility, performance, and nitrogen balance in young nellore bulls. *Transl. Animal Sci.* 3, 1205–1215. doi:10.1093/tas/txz138
- Michael, S., Mbwambo, N., Mruttu, H., Dotto, M., Ndomba, C., da Silva, M., et al. (2018). *Tanzania livestock master plan*. Nairobi, Kenya: International Livestock Research Institute ILRI.
- MLF (2018). *Tanzania livestock master plan*. Ministry of Livestock and Fisheries. Available online at: <https://www.mifugouvuvu.go.tz>.
- MLFD (2015). Tanzania livestock modernization initiative (TLMI). *Ministry Livestock Fish. Dev.* Available online at: <https://livestocklivelihoodsandhealth.org>.
- Moletta, J. L., Torrecilhas, J. A., Ornaghi, M. G., Passeti, R. A. C., Eiras, C. E., and Prado, I. N. d. (2014). Feedlot performance of bulls and steers fed on three levels of concentrate in the diets. *Acta Sci. Anim. Sci.* 36, 323–328.
- Msalya, G., Kim, E.-S., Laisser, E. L., Kipanyula, M. J., Karimuribo, E. D., Kusiluka, L. J., et al. (2017). Determination of genetic structure and signatures of selection in three strains of Tanzania shorthorn zebu, boran and Friesian cattle by genome-wide SNP analyses. *PLoS One* 12, e0171088. doi:10.1371/journal.pone.0171088
- Muetzel, S., Hannaford, R., and Jonker, A. (2024). Effect of animal and diet parameters on methane emissions for pasture-fed cattle. *Animal Prod. Sci.* 64. doi:10.1071/an23049
- Mushi, D. E. (2020). Feedlot performance of Tanzanian shorthorn zebu finished on local feed resources. *Trop. Anim. Health Prod.* 52, 3207–3216. doi:10.1007/s11250-020-02346-y
- Mushi, D. E., Eik, L. O., Bernués, A., Ripoll-Bosch, R., Sundstøl, F., and Mo, M. (2015). "Reducing GHG emissions from traditional livestock systems to mitigate changing climate and biodiversity," in *Sustainable intensification to advance food security and enhance climate resilience in Africa*. Editors L. Rattan, R. S. Bal, L. M. Dismas, K. David, O. H. David, and O. Lars (Switzerland: Springer International Publishing), 343–365.
- Mwangi, F. W., Charmley, E., Gardiner, C. P., Malau-Aduli, B. S., Kinobe, R. T., and Malau-Aduli, A. E. (2019). Diet and genetics influence beef cattle performance and meat quality characteristics. *Foods* 8, 648. doi:10.3390/foods8120648
- Oddy, V., Robards, G., and Low, S. (1983). "Prediction of *in vivo* dry matter digestibility from the fibre and nitrogen content of a feed," in *Feed information and animal production. Commonwealth agricultural bureaux*. Editors G. E. Robards and R. G. Packham (Farnham Royal, UK), 395–398.
- Pedreira, M. d.S., Oliveira, S. G. d., Primavesi, O., Lima, M. A. d., Frighetto, R. T. S., and Berchielli, T. T. (2013). Methane emissions and estimates of ruminal fermentation parameters in beef cattle fed different dietary concentrate levels. *Rev. Bras. Zootec.* 42, 592–598. doi:10.1590/s1516-35982013000800009
- Retallick, K., Bormann, J., Weaver, R., MacNeil, M., Bradford, H., Freetly, H., et al. (2017). Genetic variance and covariance and breed differences for feed intake and average daily gain to improve feed efficiency in growing cattle. *J. Animal Sci.* 95, 1444–1450. doi:10.2527/jas.2016.1260
- Salum, K. A., Laswai, G. H., and Mushi, D. E. (2024). Performance of boran and two strains of Tanzania short horn zebu cattle fed on three different diets. *Int. J. Animal Sci. Technol.* 8, 21–30. doi:10.11648/j.ijast.20240802.12
- Seif, S. K., and Kipkirui, E. (2024). Harnessing Tanzania's rangelands to mitigate methane emissions from livestock enteric fermentation. *Eur. J. Theor. Appl. Sci.* 2, 514–517. doi:10.59324/ejtas.2024.2(2).44
- Selemani, I. S., Eik, L. O., Holand, Ø., Ådnøy, T., Mtengeti, E. J., Mushi, D. E., et al. (2015). "Feeding strategies for improved beef productivity and reduced GHG emission in Tanzania: Effect of type of finish-feeding on carcass yield and meat quality of zebu steers," in *Sustainable intensification to advance food security and enhance climate resilience in Africa*. Editors R. Lal, B. R. Singh, D. L. Mwaseba, D. Kraybill, D. O. Hansen, and L. O. Eik (Switzerland: Springer), 367–382.
- Stakelum, G., and Connolly, J. (1987). Effect of body size and milk yield on intake of fresh herbage by lactating dairy cows indoors. *Ir. J. Agric. Res.* 26, 9–22.
- Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., Rosales, M., et al. (2006). *Livestock's long shadow: environmental issues and options*. Food and Agriculture Org.
- Suleiman, R. (2018). "Local and regional variations in conditions for agriculture and food security in Tanzania," in *AgriFoSe2030 report*.
- Van Soest, P. J., Robertson, J. B., and Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74, 3583–3597. doi:10.3168/jds.s0022-0302(91)78551-2
- van Wyngaard, J. D., Meeske, R., and Erasmus, L. J. (2018). Effect of concentrate level on enteric methane emissions, production performance, and rumen fermentation of Jersey cows grazing kikuyu-dominant pasture during summer. *J. Dairy Sci.* 101, 9954–9966. doi:10.3168/jds.2017-14327
- Walker, R., Martin, R., Gentry, G., and Gentry, L. (2015). Impact of cow size on dry matter intake, residual feed intake, metabolic response, and cow performance. *J. Animal Sci.* 93, 672–684. doi:10.2527/jas.2014-7702
- White, R. R., Brady, M., Capper, J. L., and Johnson, K. A. (2014). Optimizing diet and pasture management to improve sustainability of US beef production. *Agric. Syst.* 130, 1–12. doi:10.1016/j.agsy.2014.06.004