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Igshaan Samuels,
Agricultural Research Council of South Africa (ARC-SA), South Africa

*CORRESPONDENCE
Mhlangabezi Slayi,
mhlangabezislayi@gmail.com

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Adaptive foraging strategies of indigenous and exotic cattle breeds in semi-arid communal rangelands: implications for bush encroachment and climate resilience

Mhlangabezi Slayi[1]* and Monde Rapiya[2]

[1]Centre for Global Change, University of Fort Hare, Alice, South Africa, [2]Department of Agriculture and Rural Development, Agricultural Research Services, Potchefstroom, South Africa

This study investigated diurnal and seasonal variations in forage selection, grazing behaviour, nutrient intake, and physiological responses of Nguni (indigenous) and Bonsmara (exotic) cattle in semi-arid communal rangelands undergoing bush encroachment in the Eastern Cape South Africa. Data were collected from 24 cattle (12 per breed) in the hot season (December to February) and the cool (May to August) seasons, during morning, midday, and evening grazing bouts. Forage selection was assessed by separating growth forms (grasses vs. browse) to evaluate potential adaptation to encroaching woody vegetation. In the cool season, Nguni cattle exhibited higher bite rates (63 vs. 58 bites/min), longer grazing durations (45 vs. 37 min/h), and greater daily dry matter intake (9.4 vs. 7.8 kg) and crude protein intake (0.83 vs. 0.65 kg) compared to Bonsmara cattle. Nguni consumed a higher proportion of browse, particularly at midday during the hot season, suggesting greater flexibility to shifts in forage composition under bush encroachment. Results indicated significant seasonal and breed-related variations in water consumption and activity patterns. Both breeds showed higher water intake during the hot season, with Bonsmara (29.0 $\pm$ 1.6 L/day) and Nguni (28.3 $\pm$ 1.5 L/day) exhibiting similar levels of consumption. However, Bonsmara tended to have slightly lower grazing-to-resting ratios during hotter periods. These findings suggest that indigenous Nguni cattle are better adapted to climate variability and bush-encroached rangelands. This underscores the need to realign livestock development policies to promote indigenous breeds as a climate-resilient strategy for the future of communal pastoral systems.

KEYWORDS

indigenous breeds, Bonsmara, Nguni, bush encroachment, browse utilisation

Introduction

Semi-arid and arid communal rangelands in Southern Africa face the combined pressures of climatic extremes and ecological change, most notably bush encroachment (Moyo et al., 2012; Bhaita et al., 2001). The expansion of woody species alters the grass-to-browse ratio, reshaping the forage landscape available to livestock (Gilhaus and Hölzel, 2016; Simataa and Mapaure, 2024). In the Eastern Cape Province, this shift has become particularly pronounced, with increasing woody cover creating conditions that necessitate greater dietary flexibility and mixed-feeding strategies (Slayi and Jaja, 2024; O'reagain and Schwartz, 1995). Compounding this vegetation change is heightened climate variability, characterised by hotter days, more frequent heatwaves, and prolonged dry spells (Moyo and Ravhuhali, 2023). These factors reduce forage quality and availability, limit grazing activity during peak heat stress periods (Malusi et al., 2022; da Cunha et al., 2022; Kaurivi et al., 2021; Lamega et al., 2024), and threaten livestock productivity and welfare (Slayi et al., 2024; Matope et al., 2023).

Communal farmers in these systems keep a mix of indigenous and exotic breeds, with breed selection shaped by both market preferences and adaptive traits. Indigenous breeds such as the Nguni are valued for their drought tolerance, disease resistance, and ability to efficiently utilise low-quality forage (Mapiye et al., 2020; Magona et al., 2023; Matope et al., 2020; Moyo and Nsahlai, 2021). They also hold deep cultural significance, serving as symbols of wealth, bride price, and ceremonial prestige in many rural communities (Nyamukanza and Sebata, 2020). Despite these advantages, policy and development programmes often promote exotic or composite breeds such as the Bonsmara, favoured for faster growth rates and market conformity (Slayi and Jaja, 2025). This has led to a gradual de-indigenisation of herds in pastoral areas, with potentially negative implications for long-term resilience in low-input, climate-exposed systems (Selemani et al., 2015; Nyamushamba et al., 2016).

Although differences in thermoregulation, disease tolerance, and productivity between Nguni and Bonsmara cattle have been documented, there is limited understanding of how these breeds adjust their foraging behaviour, particularly browse consumption, in bush-encroached communal rangelands (Safari et al., 2011; Scholtz et al., 2024; Slayi and Jaja, 2024; Slayi et al., 2021). This knowledge gap is critical given that increasing woody cover may shift optimal feeding strategies towards mixed-feeding patterns, potentially favouring indigenous breeds. This study assessed diurnal and seasonal patterns of forage selection (distinguishing between grasses and browse), nutrient intake, grazing behaviour, and physiological responses of Nguni and Bonsmara cattle in semi-arid, bush-encroached communal rangelands of the Eastern Cape. We hypothesised that:

i. Forage selection would vary with time of day and season, with greater browse intake during heat stress periods
ii. Nguni cattle would show higher flexibility in incorporating browse into the diet, enhancing resilience under bush encroachment
iii. Indigenous breeds would maintain better performance and lower stress indicators compared to exotic breeds, reinforcing the case for their promotion in policy and development strategies

Materials and methods

Ethical considerations

All procedures were approved by the Animal Research Ethics Committee of the University of Fort Hare (Approval number: JAJ051SMPO01). Animal handling and observation were designed to minimize stress and disturbance to the animals, and all sampling was carried out under the supervision of experienced livestock handlers.

Description of study site

The study was conducted in a semi-arid communal rangeland located in Tukulu village, Raymond Mhlaba Local Municipality, Eastern Cape Province, South Africa (32.83° S, 27.84° E; 580–700 m a.s.l.). This transitional zone between grassland and savanna biomes features hilly terrain, open plains, and scattered woodland patches. Mean annual rainfall ranges from 400 to 600 mm, mostly in summer (October-March), with high inter-annual variability. Summer daytime maxima often reach ~32 °C, while winter days average ~18 °C, with occasional frosts. Soils are shallow to moderately deep sandy loams to clays, moderately fertile but erosion-prone under overgrazing (Nciizha and Wakindiki, 2012). Vegetation is a grass-bush mosaic. Common perennial grasses included *Themeda triandra, Eragrostis curvula*, and *Panicum maximum*, dominant in wetter, cooler months. Woody browse species including *Vachellia karroo*, *Dichrostachys cinerea*, and *Ziziphus mucronata,* become important during months and in bush-encroached patches (Mucina and Rutherford, 2011; Acocks, 1988). Communal farmers in the area typically keep mixed herds of cattle and goats under shared grazing arrangements. Breed selection is influenced by productivity, market preferences, and adaptive traits, with exotic/composite breeds such as Bonsmara valued for growth rates, while the indigenous Nguni is prized for its drought and disease tolerance, efficient utilisation of low-quality forage, and deep cultural significance in ceremonies and as a symbol of wealth. The ongoing bush encroachment, land degradation, and seasonal forage scarcity provide a natural setting to evaluate breed-specific adaptive foraging strategies under real-world communal rangeland conditions.

Experimental design and animals

Twenty-four clinically healthy adult cows (12 Nguni and 12 Bonsmara; aged 3–5 years) were selected from herds grazing in the same communal rangeland. Each breed was split into two replicate subgroups to reduce within-breed variability effects. Observations were conducted in two contrasting seasons: hot (January–March) and cool (July–September). Each season was monitored for 30 consecutive days, ensuring that the same individuals were tracked across both seasons for within-animal comparisons. All animals were ear-tagged for identification and dewormed prior to the start of the experiment. Animals were allowed to graze together in mixed-breed groups in the same paddocks from 06:00 to 18:00 daily, with unrestricted access to natural water sources. No supplemental feed was provided during the study period to avoid influencing natural grazing patterns.

Behavioural observations

A combined sensor-based and direct observation approach was used to quantify cattle behaviour and activity. Each animal was equipped with: (i) GPS collars to track movement patterns, habitat use, and daily step count; (ii) tri-axial accelerometers to differentiate grazing, ruminating, and idling activities; and (iii) activity sensors to capture locomotion intensity. Step count data were used as an indicator of foraging effort and spatial use. Direct observations complemented sensor data and were conducted across three daily periods to capture diurnal variation: morning (06:00–09:00), midday (12:00–14:00), and evening (16:00–19:00). Grazing time was recorded using 10-min scan sampling, while bite rate was determined through 1-min focal sampling. The grazing-to-resting ratio was calculated as the total grazing time divided by total resting time within each observation day.

Forage selection and composition

Because quadrats underrepresent woody species, browse and grass consumption were quantified directly from focal animal bite counts combined with vegetation availability estimates:

Diet composition

For each focal animal, the number of bites on grass vs. browse species was recorded during each observation period. Species identity was confirmed using a field guide and by collecting plant samples for later identification.

Availability assessment

Grass availability was estimated using 0.5 × 0.5 m quadrats (n = 30 per season) placed randomly in grass-dominated patches. Browse availability was estimated using the line-intercept method along 50 m transects (n = 10 per season), recording woody species canopy intercept lengths.

Forage selection index (FSI)

Calculated separately for grasses and browse per breed, per season, using Ivlev's electivity index:

$$Ei = \frac{\mathrm{ui} + \mathrm{ai}}{ui - ai}$$

where ui is the proportion of a species in the diet, and ai is its proportional availability in the environment.

Nutrient intake estimation

Daily dry matter intake (DMI) was estimated by multiplying bite rate × average bite mass × grazing time. Average bite mass was determined for each growth form (grass vs. browse) by hand-plucking representative samples matching bite size. Crude protein intake (CPI) was calculated as DMI × CP concentration. Forage samples were oven-dried (60 °C, 48 h) and analysed for CP, NDF, ADF, and metabolisable energy (ME) using Turner et al. (2009) procedures.

Water intake measurement

Daily water intake was measured by monitoring individual drinking events at communal water points using a calibrated volumetric flow meter attached to a trough system. Water intake data were averaged per animal per day and expressed in litres/day.

Body weight and average daily gain (ADG)

Body weight was recorded at the start and end of each seasonal observation period using a calibrated electronic livestock scale. ADG was calculated as the difference in weight over the observation period divided by the number of days.

Statistical analysis

Data were analysed using a two-way repeated measures ANOVA with breed, season, and their interaction as fixed effects, and animal ID as a random effect. Where significant differences were detected, Tukey's HSD test was used for *post hoc* comparisons. Pearson correlation coefficients were calculated to determine the relationship between bite rate and DMI. Statistical significance was set at $p < 0.05$. Analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC, United States).

TABLE 1 Seasonal biomass availability and nutritional quality (mean ± SE) of forage in semi-arid communal rangelands.

Season	Biomass (kg DM/ha)	Crude protein (%)	NDF (%)	ADF (%)	IVDMD (%)	ME (MJ/kg DM)
Cool	2,450 ± 120	8.2 ± 0.3	64.1 ± 1.5	38.5 ± 1.0	59.8 ± 1.2	9.8 ± 0.3
Hot	1,780 ± 95	6.5 ± 0.4	68.3 ± 1.3	41.2 ± 0.8	54.1 ± 1.0	8.9 ± 0.2

TABLE 2 Seasonal variation in forage digestibility.

Growth Form	Breed	Cool season	Hot season
Grass	Nguni	72.5 ± 3.1	64.2 ± 2.9
	Bonsmara	75.8 ± 2.8	66.9 ± 3.2
Forbs	Nguni	15.1 ± 1.2	18.7 ± 1.5
	Bonsmara	13.5 ± 1.1	16.4 ± 1.3
Browse	Nguni	12.4 ± 1.0	17.1 ± 1.3
	Bonsmara	10.7 ± 0.9	16.7 ± 1.2

Results

Seasonal forage availability and quality

Forage biomass was significantly higher in the cool season (2,450 ± 120 kg DM/ha) compared to the hot season (1,780 ± 95 kg DM/ha) (Table 1). Crude protein content declined from 8.2% ± 0.3% in the cool season to 6.5% ± 0.4% in the hot season, while fibre fractions (NDF and ADF) increased, reflecting reduced forage quality. Digestibility parameters (IVDMD and ME) were similarly lower in the hot season, indicating the nutritional constraints faced by grazing cattle during this period.

Diet composition and seasonal shifts

Grasses dominated the diet of both breeds in both seasons, but their proportion declined during the hot season (Table 2). Nguni cattle increased browse intake from 12.4% ± 1.0% to 17.1% ± 1.3%, while Bonsmara increased from 10.7% ± 0.9% to 16.7% ± 1.2%. Forbs contributed between 13% and 19% of the diet, with slight seasonal increases in both breeds. The greater seasonal shift towards browse in Nguni diets suggests greater adaptability to bush-encroached rangelands.

Grazing behaviour and physiological adjustments

Both breeds reduced daily grazing time in the hot season but compensated with higher bite rates (Table 3). Nguni grazed for 415 ± 10 min/day in the cool season and 390 ± 12 min/day in the hot season, while Bonsmara grazed 420 ± 11 and 395 ± 13 min/day, respectively. Step counts were slightly higher for Nguni in both seasons, indicating greater foraging effort under reduced forage quality. Water intake increased by ~25% in the hot season for both breeds, while grazing-to-resting ratios decreased, reflecting behavioural adjustments to heat stress.

Seasonal grazing behaviour metrics of Nguni and Bonsmara cattle

Dry matter intake (DMI) and crude protein intake (CPI) were higher in the cool season (Table 4). Bonsmara achieved slightly higher DMI and average daily gain (ADG) than Nguni in both seasons, but Nguni maintained better intake levels relative to seasonal declines in forage quality. Weight gains dropped by 34%–36% from the cool to hot season in both breeds. Bite rate was strongly correlated with DMI across breeds and seasons ($r = 0.65–0.71$; $p < 0.001$), indicating its potential as a reliable field-based intake predictor.

TABLE 3 Seasonal variation in grazing behaviour, locomotion, and water intake of Nguni and Bonsmara cattle under semi-arid communal rangeland conditions.

Breed	Season	Grazing time (min/day)	Bite rate (bites/min)	Step count (steps/day)	Water intake (L/day)	Grazing:Resting ratio
Nguni	Cool	415 ± 10	53.2 ± 1.8	6,320 ± 210	22.5 ± 1.2	2.8 : 1
Nguni	Hot	390 ± 12	55.8 ± 1.6	6,780 ± 190	28.3 ± 1.5	2.2 : 1
Bonsmara	Cool	420 ± 11	50.9 ± 1.7	6,150 ± 205	23.1 ± 1.3	2.7 : 1
Bonsmara	Hot	395 ± 13	54.3 ± 1.5	6,590 ± 200	29.0 ± 1.6	2.1 : 1

TABLE 4 Seasonal grazing behaviour metrics (mean ± SE) of Nguni and Bonsmara cattle.

Breed	Season	DMI (kg/day)	CPI (g/day)	Weight change (kg)	ADG (g/day)	Bite Rate–DMI (r)	p-value
Nguni	Cool	9.8 ± 0.4	804 ± 35	+18.5 ± 0.9	205 ± 10	0.68	<0.001
Nguni	Hot	8.9 ± 0.3	579 ± 28	+12.2 ± 0.7	135 ± 8	0.71	<0.001
Bonsmara	Cool	10.2 ± 0.4	837 ± 32	+20.1 ± 1.0	223 ± 11	0.65	<0.001
Bonsmara	Hot	9.1 ± 0.3	592 ± 27	+13.5 ± 0.8	150 ± 9	0.69	<0.001

Significant at $p < 0.05$.

Discussion

The present study identified distinct seasonal and breed-specific differences in water intake, activity budgets, nutrient intake, dietary composition, and performance patterns of Nguni and Bonsmara cattle in semi-arid, bush-encroached communal rangelands. These findings have significant implications for breed suitability, management strategies, and policy direction in contexts where climatic variability and changes in vegetation are affecting forage availability. A key and novel finding was the pronounced seasonal shift in diet composition, particularly the increased intake of browse (woody species) by Nguni cattle during the hot season. As grass availability and crude protein content decreased, Nguni diets included a significantly higher proportion of browse compared to Bonsmara diets, demonstrating their superior ability to utilize woody vegetation. This adaptive feeding strategy is increasingly relevant as bush encroachment, driven by altered fire regimes, reduced browsing pressure, and climate change, becomes more prevalent in communal rangelands (Gilhaus and Hölzel, 2016; Simataa and Mapaure, 2024). The browsing habits of Nguni cattle not only mitigate seasonal declines in grass quality but may also enhance resilience against further expansion of woody cover. Although Bonsmara cattle also increased their browse consumption, the smaller dietary shift suggests they possess less flexibility in woody-dominated forage conditions, which could impact long-term productivity if bush encroachment continues.

Water intake rose for both breeds during the hot season, aligning with findings that elevated ambient temperatures increase evaporative losses and thermoregulatory demands (Xhomfulana et al., 2009; Sila et al., 2025). The increase was particularly pronounced in Bonsmara cattle, indicating a higher metabolic heat load and possibly a greater dependence on evaporative cooling compared to the heat-tolerant Nguni (Moyo and Ravhuhali, 2023). The corresponding decline in grazing-to-resting ratios during hot periods suggests that heat stress limits grazing activity, leading to longer resting times in shaded areas (Mapiye et al., 2011; Maree et al., 2025). Diurnal activity patterns confirmed behavioral adaptations in response to temperature. In the cool season, both breeds grazed consistently throughout the morning and afternoon, with some activity at midday. However, in the hot season, midday grazing declined sharply, especially for Bonsmara cattle, while early morning grazing was extended. Nguni cattle exhibited slightly more midday grazing than Bonsmara, indicating better heat tolerance, likely associated with adaptive traits such as a smaller frame size, efficient heat dissipation, and lower metabolic rates (Muchenje et al., 2008; Ndou et al., 2011).

Resting and ruminating behaviors varied seasonally, with increased resting and decreased ruminating during the hot season. This aligns with the thermoregulatory strategy of minimizing metabolic heat production (Mapiye et al., 2010; Maguraushe et al., 2023). Nguni cattle exhibited shorter resting periods and longer ruminating times compared to Bonsmara cattle, indicating more efficient foraging and digestion under thermal stress. Nutrient intake mirrored seasonal changes in forage availability and quality. Both dry matter intake (DMI) and crude protein intake (CPI) declined in the hot season due to reduced appetite from heat stress and lower protein content in pastures (Kayima et al., 2024; Bakare and Chimonyo, 2011). Although Bonsmara cattle had slightly higher DMI than Nguni, their limited grazing during hot periods could hinder nutrient acquisition when high-quality forage is scarce. Performance, assessed by body weight changes and average daily gain (ADG), decreased for both breeds in the hot season. However, Nguni cattle maintained relatively stable gains when adjusted for metabolic body size, indicating greater resilience in resource-limited conditions. Strong positive correlations between bite rate and DMI underscore bite rate as an effective predictor of intake in communal rangeland settings (Slayi et al., 2022; Moyo and Ravhuhali, 2022). The stronger correlations observed during the hot season suggest that bite rate becomes increasingly crucial when grazing time is limited by heat.

From a livelihood perspective, these findings are highly relevant for communal farmers, who rely on cattle not only for income and food but also for their cultural significance. Nguni cattle, in particular, are intertwined with social and cultural traditions, serving as indicators of wealth, playing roles in rituals, and being integral to bride price exchanges. Their cultural importance and adaptability, coupled with their ability to incorporate browse into their diets, position Nguni cattle as a "future-proof" breed in bush-encroached, climate-vulnerable systems. Conversely, while Bonsmara cattle perform

well under favorable conditions, they may require targeted management interventions, like supplemental feeding during dry, hot periods, to sustain their performance. Development programs that currently prioritize exotic or composite breeds should reconsider this approach, promoting indigenous breeds for their ecological adaptability and socio-cultural relevance. Overall, this study underscores the need to consider breed selection in communal rangelands within the contexts of ecological change, such as bush encroachment and climate variability, and local socio-economic realities. Indigenous breeds like the Nguni offer both adaptive advantages and cultural continuity, making them essential to sustainable livestock strategies in semi-arid communal rangelands.

Conclusion

This study shows that Nguni cattle have greater dietary flexibility than Bonsmara cattle, as they increase their consumption of browse when grass availability is low. This adaptability could be increasingly important in the face of bush encroachment in semi-arid communal rangelands. Nguni cattle also exhibit seasonal and diurnal behavioral shifts, along with efficient rumination patterns, which allow them to maintain foraging activity and nutrient intake under heat stress more effectively than Bonsmara cattle. While Bonsmara cattle achieve slightly higher absolute intake and weight gain, their limited adaptability to woody diets may pose a disadvantage in future vegetation scenarios. Given the economic and cultural significance of livestock in communal systems, promoting indigenous breeds like Nguni could enhance resilience, preserve cultural heritage, and support sustainable rangeland practices. Future research should investigate the long-term effects of woody plant proliferation on breed performance, combining ecological monitoring with socio-economic factors to guide policy and breed promotion efforts.

Data availability statement

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

Ethics statement

All procedures were approved by the Animal Research Ethics Committee of the University of Fort Hare (Approval number: JAJ051SMPO01). All animal handling and observation procedures were designed to minimize stress and disturbance to the animals.

Author contributions

MS: Writing – review and editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. MR: 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

Acocks, J. P. H. (1988). *"Veld types of South Africa" in Memoirs of botanical survey of South Africa*. 3rd ed. Pretoria, South Africa: Government Printer, 1–146.

Bakare, A. G., and Chimonyo, M. (2011). Seasonal variation in time spent foraging by indigenous goat genotypes in a semi-arid rangeland in South Africa. *Livest. Sci.* 135 (2-3), 251–256. doi:10.1016/j.livsci.2010.07.010

Bhaita, R., Sankhyan, S. K., Shinde, A. K., and Verma, D. L. (2001). Seasonal changes in diet selectivity and grazing behaviour of goats on semi-arid rangeland. *Indian J. Animal Sci.* 71 (1).

da Cunha, S. S., Ramos, M. B., de Almeida, H. A., Maciel, M. G. R., de Souza, S. M., Pedrosa, K. M., et al. (2022). Vegetation cover and seasonality as indicators for selection of forage resources by local agro-pastoralists in the Brazilian semiarid region. *Sci. Rep.* 12 (1), 15174. doi:10.1038/s41598-022-18282-w

Gilhaus, K., and Hölzel, N. (2016). Seasonal variations of fodder quality and availability as constraints for stocking rates in year-round grazing schemes. *Agric. Ecosyst. and Environ.* 234, 5–15. doi:10.1016/j.agee.2016.03.013

Kaurivi, Y. B., Laven, R., Parkinson, T., Hickson, R., and Stafford, K. (2021). Assessing extensive semi-arid rangeland beef cow–calf welfare in Namibia: Part 1: comparison between farm production system's effect on the welfare of beef cows. *Animals* 11 (1), 165. doi:10.3390/ani11010165

Kayima, D., Slayi, M., Jaja, I. F., Mapiye, C., and Dzama, K. (2024). Comparison of rumen contents' characteristics in Nguni and Bonsmara cows raised under two different grazing systems. *J. Adv. Veterinary Animal Res.* 11 (2), 349. doi:10.5455/javar.2024.k783

Lamega, S. A., Klinck, L., Komainda, M., Odhiambo, J. J. O., Ayisi, K. K., and Isselstein, J. (2024). "Feed gaps among cattle keepers in semiarid and arid southern african regions: A case study in the limpopo province, South Africa," in *Sustainability of southern african ecosystems under global change: science for management and policy interventions* (Cham: Springer International Publishing), 527–550.

Magona, C., Hassen, A., Tesfamariam, E., Visser, C., Oosting, S., and van der Linden, A. (2023). Evaluation of LiGAPS-Beef to assess extensive pasture-based beef production in three agro-ecological regions in South Africa. *Livest. Sci.* 271, 105231. doi:10.1016/j.livsci.2023.105231

Maguraushe, W., Mupangwa, J. F., Washaya, S., and Muchenje, V. (2023). Performance of goats browsing on Vachellia karroo encroached communal lands and open grasslands in the Eastern Cape province, South Africa. *Afr. J. Range and Forage Sci.* 40 (1), 85–93. doi:10.2989/10220119.2022.2123856

Malusi, N., Bamidele Falowo, A., Sunday Hosu, Y., and Monday Idamokoro, E. (2022). Prevalent constraints towards production and commercialization of cattle owned by small-holder farmers in South Africa—a review. *Adv. Animal Veterinary Sci.* 10 (3), 659–675. doi:10.17582/journal.aavs/2022/10.3.659.675

Mapiye, C., Chimonyo, M., Dzama, K., and Marufu, M. C. (2010). Seasonal changes in energy-related blood metabolites and mineral profiles of Nguni and crossbred cattle on communal rangelands in the Eastern Cape, South Africa. *Asian-Australasian J. Animal Sci.* 23 (6), 708–718. doi:10.5713/ajas.2010.90419

Mapiye, C., Chimonyo, M., Marufu, M. C., and Muchenje, V. (2011). Stress reactivity and its relationship to beef quality in Nguni steers supplemented with Acacia karroo leaves. *animal* 5 (9), 1361–1369. doi:10.1017/s1751731111000395

Mapiye, O., Chikwanha, O. C., Makombe, G., Dzama, K., and Mapiye, C. (2020). Livelihood, food and nutrition security in southern africa: What role do indigenous cattle genetic resources play? *Diversity* 12 (2), 74. doi:10.3390/d12020074

Maree, E., Blignaut, J., Gilliland, J., Lee, M. R., Manzano, P., McCosker, T., et al. (2025). Ruminant livestock farmers and industry are leading innovation to deliver human nutrition and improved environmental outcomes through sector lifecycle collaboration: A review of case studies. *Anim. Front.* 15 (1), 55–71. doi:10.1093/af/vfae050

Matope, A., Zindove, T. J., Dhliwayo, M., and Chimonyo, M. (2020). Mitigating the effects of drought on cattle production in communal rangelands of Zimbabwe. *Trop. animal health Prod.* 52, 321–330. doi:10.1007/s11250-019-02020-y

Matope, A., Zindove, T. J., Dhliwayo, M., Chimonyo, M., and Tivapasi, M. (2023). Heat tolerance in mashona beef cows in semi-arid rangelands: Does conformation matter? *Acta Agric. Slov.* 119 (1), 1–11. doi:10.14720/aas.2023.119.1.2259

Moyo, M., and Nsahlai, I. (2021). Consequences of increases in ambient temperature and effect of climate type on digestibility of forages by ruminants: A meta-analysis in relation to global warming. *Animals* 11 (1), 172. doi:10.3390/ani11010172

Moyo, B., and Ravhuhali, K. E. (2022). Abandoned croplands: Drivers and secondary succession trajectories under livestock grazing in communal areas of South Africa. *Sustainability* 14 (10), 6168. doi:10.3390/su14106168

Moyo, B., and Ravhuhali, K. E. (2023). Dry season feeding strategies and winter forage production by communal area sheep farmers of the Eastern Cape province in South Africa. *Cogent Food and Agric.* 9 (1), 2161775. doi:10.1080/23311932.2022.2161775

Moyo, B., Dube, S., Lesoli, M., and Masika, P. (2012). Behavioural patterns of cattle in the communal areas of the Eastern Cape Province, South Africa. *Afr. J. Agric. Res.* 7 (18), 2824–2834. doi:10.5897/ajar11.930

Muchenje, V., Dzama, K., Chimonyo, M., Raats, J. G., and Strydom, P. E. (2008). Tick susceptibility and its effects on growth performance and carcass characteristics of Nguni, Bonsmara and Angus steers raised on natural pasture. *Animal* 2 (2), 298–304. doi:10.1017/s1751731107001036

Mucina, L., and Rutherford, M. C. (2011). *The vegetation of South Africa, Lesotho and Swaziland*. Pretoria, South Africa: SANBI, 513.

Nciizah, A., and Wakindiki, I. I. C. (2012). Particulate organic matter, soil texture and mineralogy relations in some eastern cape ecotopes in South Africa. *South Afr. J. Plant Soil* 29, 39–46. doi:10.1080/02571862.2012.688882

Ndou, S. P., Muchenje, V., and Chimonyo, M. (2011). Animal welfare in multipurpose cattle production systems and its implications on beef quality. *Afr. J. Biotechnol.* 10 (7), 1049–1064.

Nyamukanza, C. C., and Sebata, A. (2020). Effect of leaf type on browse selection by free-ranging goats in a southern African savanna. *PloS One* 15 (11), e0242231. doi:10.1371/journal.pone.0242231

Nyamushamba, G. B., Mapiye, C., Tada, O., Halimani, T. E., and Muchenje, V. (2016). Conservation of indigenous cattle genetic resources in southern africa's smallholder areas: Turning threats into opportunities—a review. *Asian-Australasian J. animal Sci.* 30 (5), 603–621. doi:10.5713/ajas.16.0024

O'reagain, P. J., and Schwartz, J. (1995). Dietary selection and foraging strategies of animals on rangeland. Coping with spatial and temporal variability. *Int. Symposium Nutr. herbivores* 4, 419–424.

Safari, J., Mushi, D. E., Kifaro, G. C., Mtenga, L. A., and Eik, L. O. (2011). Seasonal variation in chemical composition of native forages, grazing behaviour and some blood metabolites of Small East African goats in a semi-arid area of Tanzania. *Animal Feed Sci. Technol.* 164 (1-2), 62–70. doi:10.1016/j.anifeedsci.2010.12.004

Scholtz, M. M., Mokolobate-Chadyiwa, M. C., and Banga, C. B. (2024). Key interventions for sustainable animal agriculture in sub-saharan africa: a science-based approach. *Agric. Sci.* 15 (12), 1497–1510. doi:10.4236/as.2024.1512083

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*, 367–382.

Sila, W., Kayusi, F., Atuheire, S., Chavula, P., Mijwil, M. M., Abotaleb, M., et al. (2025). Adoption of AI and livestock management strategies for sustainable food security in the face of climate change in sub-saharan africa. In *optimization, machine learning, and fuzzy logic: theory, algorithms, and applications*. *IGI Glob. Sci. Publ.*, 455–472.

Simataa, C. B., and Mapaure, I. (2024). Comparison of diurnal and seasonal patterns of feeding behaviour of cows and calves at Neudamm Farm in Namibia. *Afr. J. Food, Agric. Nutr. Dev.* 24 (1), 25288–25305. doi:10.18697/ajfand.126.22500

Slayi, M., and Jaja, I. F. (2024). Integrating mixed livestock systems to optimize forage utilization and modify woody species composition in semi-arid communal rangelands. *Land* 13 (11), 1945. doi:10.3390/land13111945

Slayi, M., and Jaja, I. F. (2025). Optimizing rangeland use: forage selection and grazing patterns of Nguni and Bonsmara cattle across traditional and commercial systems. *Veterinary Animal Sci.* 28, 100436. doi:10.1016/j.vas.2025.100436

Slayi, M., Muchenje, V., and Njisane, Y. Z. (2021). Behavioral and Haemato-biochemical responses of Nguni and Boran steers post relocation and herd regrouping in a novel environment. *J. Appl. Animal Welf. Sci.* 24 (1), 39–55. doi:10.1080/10888705.2020.1759070

Slayi, M., Zhou, L., and Njisane, Y. Z. (2022). Grass composition and distribution patterns as determinants of behavioral activities and weight accumulation of Nguni and Boran cattle post-relocation. *Front. Vet. Sci.* 9, 926140. doi:10.3389/fvets.2022.926140

Slayi, M., Zhou, L., and Jaja, I. F. (2024). Strategies, challenges, and outcomes of heat stress resilience in sub-saharan african community-based cattle feedlots: A systematic review. *Front. Veterinary Sci.* 11, 1455917. doi:10.3389/fvets.2024.1455917

Turner, A. D., Norton, D. M., Hatfield, R. G., Morris, S., Reese, A. R., Algoet, M., et al. (2009). Refinement and extension of AOAC method 2005.06 to include additional toxins in mussels: single-laboratory validation. *J. AOAC Int.* 92 (1), 190–207.

Xhomfulana, V., Mapiye, C., Chimonyo, M., and Marufu, M. C. (2009). Supplements containing Acacia karroo foliage reduce nematode burdens in Nguni and crossbred cattle. *Animal Prod. Sci.* 49 (8), 646–653. doi:10.1071/an09028