



Strategic Morphometric Selection of Replacement Heifers in Extensive Tropical Systems: Insights from Pastoral Haut-Lomami Ranch, Democratic Republic of Congo

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Abstract: In tropical cattle systems with limited resources, selecting replacement heifers remains challenging due to restricted access to advanced technologies. This study proposes a practical, dual-criterion approach that combines skeletal scoring and morphometric clustering to improve selection decisions. During the 2014 mating season, a total of 200 crossbred beef heifers were evaluated at the Pastorale Haut-Lomami ranch in the Democratic Republic of Congo. Morphometric traits included live weight, wither height, rump height, chest circumference and estimated adult weight. Skeletal scores were categorized as Small (<4), Medium (4–6) or Large (>6).

Using Gower's coefficient and k-means clustering, three distinct groups were identified. Cluster 1 (n = 106) exhibited balanced morphology, medium skeletal scores (mean 4.43) and adequate maturity (>60% of the estimated adult weight). Cluster 2 (n = 35) had large skeletal frames (mean 5.60), but lower maturity levels (60.9%). Cluster 3 (n = 59) had small skeletal scores (mean 3.21) but the highest maturity percentage (70.6%), indicating early growth potential.

These findings suggest that combining frame scoring with morphometric clustering enables more precise classification and the development of tailored reproductive strategies. This method can support informed selection and sustainable herd management even in low-input systems.

Keywords: beef heifers, frame score, morphometric traits, cluster analysis, tropical cattle, reproductive maturity

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I. INTRODUCTION

Pastoralism is one of the most important economic activities in the former Katanga province of the Democratic Republic of Congo. The region covers almost 10% of the country's land area (approximately 5 million hectares), 1.85 million of which is made up of natural pastures [1]. The region has traditionally accounted for over 75% of the national herd of ranch cattle. However, only a few ranches remain today. GRELKA, Pastorale et Élevages des Salvatoriens. The Pastorale ranch in Haut-Lomami, for example, covers 216,000 hectares and provides a variety of forage, including *Hypparrhenia confinis*, *Panicum maximum*, *Loudetia arundinacea*, *Andropogon schirensis*, *Brachiaria brizantha*, *Cenchrus ciliaris*, *Andropogon gayanus*, *Stylosanthes guyanensis*, *Brachiaria ruziziensis*, *Cynodon dactylon* and *Imperata cylindrica*. In this large-scale production system, replacement heifers are selected based on three criteria: a live weight of at least 300 kg, an age of three years and an absence of visible defects. However, these criteria do not consistently ensure reproductive readiness or long-term productivity. Several studies have highlighted the value of integrating morphometric traits into selection protocols to improve decision-making in beef cattle management [2, 3].

This study evaluates the effectiveness of the current method used to select replacement heifers at the Haut-Lomami ranch, analyzing morphometric data from a cohort of replacement heifers. The aim is to determine whether combining skeletal scoring and cluster-based classification could improve the selection of replacement

heifers and enable more strategic reproductive management. The goal is to improve the value and performance of future generations in low-input tropical systems.

II. MATERIALS AND METHODS

2.1 STUDY SITE AND BREEDING CONTEXT

The study was conducted at the Pastorale du Haut-Lomami ranch in the province of Haut-Lomami in the Democratic Republic of Congo. Spanning 216,000 hectares, the ranch has a large-scale breeding system focused solely on beef production. Under the traditional kraaling system, cattle are kept in enclosures at night and allowed to graze freely during the day. Mating is uncontrolled and nutritional supplementation is limited to salt and minerals. The herd comprises animals with a variety of genetic histories and is categorized into breed types according to dominant morphological characteristics due to long-standing crossbreeding techniques.

2.2 STUDY POPULATION AND SAMPLING CRITERIA

During the mating season in November 2014, which also marked the beginning of the rainy season, a sample of 200 three-year-old heifers was chosen for the study. The animals were selected according to the standard operating criteria employed at the ranch and were sourced from the Kankundwe fattening sector.

The criteria included a live weight of at least 300 kg and an absence of physical flaws; the teats were in plain sight.

Based on phenotypic dominance, the breed was classified as follows: 29 Simmental-type, 54 Brahman-type and 117 Afrikaner-type heifers. Due to outlier data, one Brahman-type heifer was excluded from the analysis.

2.3 DATA COLLECTION PROTOCOL

Biometric measurements were collected in accordance with the phenotypic characterization guidelines established by the Food and Agriculture Organization (FAO) in 2012 [10]. To ensure accurate measurements and the safety of the animals, they were immobilized in a handling tunnel during data collection. The following morphometric variables were recorded: Live weight (LW) was measured using a Maréchalle mechanical scale with a capacity range of 1–1500 kg. Height at the withers (HW) and hip height (HH) were determined using a vertical measuring stick. Pelvic width (PW), chest circumference (CC) and body length (BL) were measured using a flexible graduated tape. All instruments were calibrated prior to use and measurements were taken by trained personnel to minimize observer bias.

2.4 DERIVED INDICATORS AND CLASSIFICATION CRITERIA

Several derived indicators were calculated to assess the skeletal development and reproductive suitability of heifers. Frame score was estimated using hip height and age, in accordance with the Beef Improvement Federation's standards for females over 24 months of age [4]. Estimated adult weight was derived from skeletal score and age, based on the predictive model proposed by Dhuyvetter [5]. To evaluate developmental status at the time of selection, the percentage of adult weight was calculated as the ratio of live weight to estimated adult weight. Additionally, the live weight-to-hip height ratio was used as a proxy for developmental balance and structural proportionality. Heifers were classified into three skeletal categories according to frame score thresholds [5]: Small: score <4; Medium: score 4–6; Large: score >6.

Reproductive readiness was interpreted in line with the recommendations of Patterson et al. [6], who suggest that heifers should attain 60–65% of their estimated adult weight at the start of the breeding period. Troxel and Gadberry [7] further emphasize the reproductive efficiency of heifers with moderate frame scores (4–6), aligning skeletal development with optimal physiological maturity.

2.5 STATISTICAL ANALYSES

Statistical analyses were performed using R software (version 3.4.2 x64) via the Rcmdr graphical interface (version 2.4-1). To evaluate the effect of breed type on morphometric traits, a Type II analysis of variance (ANOVA) was conducted using the `lm()` function. Least squares means and their respective standard errors were then calculated to determine trait differences between breed type groups.

To explore morphological variability, the Gower coefficient was used to compute the dissimilarity between each pair of observations in the dataset, which included both quantitative variables (e.g. body dimensions and live weight) and categorical variables (e.g. breed type). Based on the resulting dissimilarity matrix, a K-means clustering algorithm was applied to classify the heifers into homogeneous groups. The optimal number of clusters was determined using the `NbClust` package [8], which evaluates multiple clustering indices to identify the most stable partition. A descriptive summary of each cluster was generated using the `compareGroups()` function to allow comparative profiling of morphometric and categorical traits across clusters.

III. RESULTS

3.1. BODY MEASUREMENTS ACCORDING TO BREED TYPE

Table 1 shows the body measurements of heifers categorized by breed. Analysis of the morphometric data of replacement heifers shows no significant differences between breeds in terms of linear dimensions (rump height, withers height, pelvic width and ischio-scapular length), skeletal score or estimated adult weight. However, Afrikaner-type heifers are distinguished by significantly higher live weight, chest circumference, live weight-to-rump height ratio, and percentage of adult weight ($p < 0.05$). This reflects body development that is more advantageous for selection in extensive environments. No significant differences were observed between Brahman-type and Simmental-type heifers, confirming their morphological homogeneity.

Table 1. Least squares means, and standard errors of weight and body measurements by racial type (n=199) of replacement heifers raised at the Haut-Lomami Pastoral Ranch

Paramètre	Afrikaner-type (n=117)	Brahman-type (n=53)	Simmental-type (n=29)
Height at the rump (cm)	128.63 ± 0.41 ^a	128.34 ± 0.61 ^a	128.14 ± 0.83 ^a
Height at withers (cm)	131.56 ± 0.43 ^a	131.64 ± 0.63 ^a	130.90 ± 0.85 ^a
Pelvis width (cm)	43.09 ± 0.24 ^a	42.13 ± 0.35 ^a	42.34 ± 0.48 ^a
Ischiocapular length (cm)	142.28 ± 0.71 ^a	142.91 ± 1.06 ^a	141.03 ± 1.43 ^a
Chest circumference (cm)	162.91 ± 0.41 ^b	158.58 ± 0.61 ^a	160.03 ± 0.83 ^a
Live weight (kg)	352.86 ± 2.45 ^b	328.81 ± 3.65 ^a	330.14 ± 4.93 ^a
Live weight/height at rump ratio	274.32 ± 1.79 ^b	256.26 ± 2.66 ^a	258.10 ± 3.60 ^a
Skeletal score	4.31 ± 0.08 ^a	4.24 ± 0.13 ^a	4.20 ± 0.17 ^a
% Adult weight	68.91 ± 0.55 ^b	64.64 ± 0.82 ^a	65.54 ± 1.11 ^a
Estimated adult weight (kg)	513.73 ± 3.81 ^a	510.55 ± 5.66 ^a	508.02 ± 7.65 ^a

a-b Means within each parameter at the same time with different superscript letters are significantly different ($p < 0.05$)

3.2 ANALYSIS OF VARIABILITY IN MEASURED TRAITS

The coefficients of variation for body measurements range from 0.027 to 0.23. Of these, the skeletal score shows the greatest variability (0.23). Characteristics related to weight demonstrate moderate variability, including live weight (0.084), the live weight/rump height ratio (0.079), estimated adult weight (0.092) and the percentage of adult weight (0.098). Other body measurements show lower variability.

3.3 CLUSTER CLASSIFICATION OF SELECTED REPLACEMENT HEIFERS

The k-means algorithm was used to group the replacement heifers into homogeneous clusters. The optimal number of clusters was determined by using 30 different indices. Of these, fifteen supported partitioning into three clusters, four indices suggested two clusters, two favored four clusters and two other indices recommended five clusters.

Based on the majority rule, the optimal number of clusters was set to three (see Figure 1).

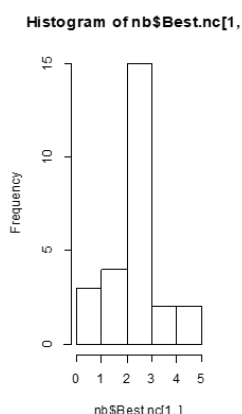


Figure 1. Number of clusters selected by 23 indices (or criteria)

3.4 DISTRIBUTION OF SELECTED REPLACEMENT HEIFERS INTO CLUSTERS

The classification analysis divided the 199 replacement heifers into three distinct clusters (see Table 2). Table 2 shows the number of individuals in each cluster, as well as the mean (\pm standard deviation) values for the morphometric variables. Significant differences ($p < 0.05$) were observed between clusters for all quantitative variables except body length. Although breed type distribution is not significantly associated with cluster membership, certain trends can be observed: Afrikaner-type heifers predominate in all three clusters, while Brahman- and Simmental-type heifers are proportionally more prevalent in clusters 2 and 3.

Table 2: Summary descriptive table by selected replacement heifers' 'cluster' (number of individuals per cluster and the mean ± standard deviation)

Parameters	Clusters						p.overall
	1 n=106		2 n=35		3 n=59		
Racial type							0.088
Africaner-type	71	(67.0%)	15	(42.9%)	31	(52.5%)	
Brahman-type	23	(21.7%)	14	(40.0%)	17	(28.8%)	
Simmental-type	12	(11.3%)	6	(17.1%)	11	(18.6%)	
Live weight (kg)	349	(22,5) ^b	350	(41,4) ^b	328	(24,8) ^a	<0.001
Ischioscapular length (cm)	143	(7,55) ^a	143	(8,11) ^a	141	(7,59) ^a	0,262
Height at withers (cm)	132	(3,22) ^b	136	(3,94) ^c	128	(4,36) ^a	<0.001
Pelvis width (cm)	43,1	(2,26) ^b	43.3	(2,69) ^b	41.7	(2,87) ^a	0.002
Height at the rump (cm)	129	(1,64) ^c	135	(3,74) ^b	124	(2,25) ^a	<0.001
Skeletal score	4.43	(0,33) ^b	5.60	(0,78) ^c	3.21	(0,45) ^a	<0.001
Chest circumference (cm)	162	(3,74) ^b	162	(6,91) ^b	159	(4,66) ^a	0.001
Live weight/height at rump ratio (kg/cm)	2.70	(0,17) ^b	2.60	(0,29) ^a	2.66	(0,21) ^b	0.032
Estimated adult weight (kg)	519	(14,8) ^b	579	(57,1) ^c	466	(20,4) ^a	<0.001
% Adult weight	67.2	(4,43) ^b	60.9	(7,89) ^a	70.6	(6,4) ^c	<0.001
% Adult weight * Skeletal Score:							<0.001
<60%large	0	(0,00 %)	8	(22,9 %)	0	(0,00 %)	
<60%medium	0	(0,00 %)	10	(28,5 %)	0	(0,00 %)	
>60%large	1	(0,90 %)	15	(42,9 %)	0	(0,00 %)	
>60%medium	105	(99,1 %)	2	(5,70 %)	0	(0,00 %)	
>60%small	0	(0,00 %)	0	(0,00 %)	59	(100 %)	

a-b Means within each parameter at the same time with different superscript letters are significantly different (p < 0.05) after pairwise. wilcox.test

Cluster 1 (n = 106) is characterized by intermediate values for most morphometric parameters. Heifers in this group have well-balanced body development, with an average live weight of 349 kg and a skeletal score of 4.43. As it includes most individuals from each breed type, this cluster is thought to represent a common morphometric profile across breeds.

Cluster 2 (n = 35) comprises heifers with the highest values for most measurements, including withers height (136 cm), rump height (135 cm), estimated adult weight (579 kg), and skeletal score (5.60). These animals display expansive morphology, indicative of late maturity or extended growth potential. However, their percentage of adult weight (60.9%) and live weight-to-rump height ratio (2.60 kg/cm) are lower than in the other clusters. This suggests that, despite their size, they may be less precocious.

Cluster 3 (n = 59) comprises replacement heifers with the smallest body dimensions and the lowest live weight (328 kg). Yet they exhibit the highest percentage of estimated adult weight (70.6%). This indicates relative precocity despite reduced morphology. All individuals in this group have low skeletal scores, which supports the idea of early maturity within a compact frame.

These findings demonstrate that morphometric clustering reveals phenotypic profiles that transcend racial classifications. Although breed types do not significantly predict cluster membership, partitioning provides valuable insights into growth patterns and developmental trajectories. This differentiation could inform management decisions, particularly in tropical systems where functional traits are often more important than breed purity.

3.5 EVALUATION OF SELECTION OF REPLACEMENT HEIFERS

The selection criteria for replacement heifers, based on a combination of skeletal score and estimated adult weight percentage, clearly categorize the chosen heifers into groups.

No heifer has a low skeletal score and a weight below 60% of the adult weight threshold, thus eliminating the least favorable profiles from the selection process.

Heifers with a low skeletal score but an adult weight exceeding 60% represent 29.7% of the sample and are exclusively in Cluster 3. This cluster reflects early weight gain despite poor conformation.

Heifers with an average skeletal score and a weight below 60% of the adult threshold are concentrated in cluster 2, accounting for 5.02% of the total sample. This profile indicates developed morphology but insufficient weight maturity. The most prevalent category (53.7%) comprises heifers with an average skeletal score and an adult

weight greater than 60%, primarily found in cluster 1. This group constitutes the optimal selection profile in extensive environments, combining conformation and precocity.

Finally, heifers with a high skeletal score are predominantly found in cluster 2 (65.8%), which confirms the morphological dominance of this group.

IV. DISCUSSION

4.1 RELEVANCE OF THE DATASET AND ANALYTICAL FRAMEWORK

Although the dataset predates the present study, the continuity of management practices at the Pastorale du Haut-Lomami ranch ensures its relevance. The stability of breeding protocols, environmental constraints and herd structure allows meaningful interpretation of morphometric and skeletal data. Combining skeletal scoring with multivariate clustering provided an analytical framework that identified phenotypic profiles supporting context-specific reproductive strategies in extensive tropical systems.

4.2 REPLACEMENT HEIFER SELECTION AND ITS IMPACT ON HERD PRODUCTIVITY

The selection and development of replacement heifers is critical for maximizing herd productivity, particularly in production systems where nutritional stress and delayed physiological maturity are common. Age at first calving is among the key selection criteria that play a pivotal role in shaping cow size, reproductive longevity, and cumulative calf output [9]. In tropical cattle systems, *Bos indicus* heifers typically reach first calving at around 44 months of age, whereas *Bos taurus* and crossbred types calve at approximately 34 months [10].

In the Haut-Lomami region, replacement heifers are selected at 36 months of age to mitigate postpartum weight loss in primiparous cows. This timing supports a more balanced physiological transition, as young cows must sustain lactation, continue to grow and recover energy reserves concurrently [11]. This approach aligns with adaptive management strategies aimed at enhancing reproductive efficiency and resilience in extensive systems.

4.3 ENVIRONMENTAL INFLUENCE ON HEIFERS' DEVELOPMENT

Bos indicus cattle exhibit genetic adaptations to seasonal fluctuations in forage availability, which contribute to delayed puberty and altered growth trajectories [12]. These physiological traits necessitate tailored management strategies to ensure reproductive readiness in replacement heifers. It is generally recommended that heifers attain at least 60% of their mature body weight prior to first breeding, a threshold that supports hormonal maturation and reproductive success [13]. In extensive systems characterized by prolonged dry seasons and variable forage quality, achieving this target often requires strategic nutritional intervention, particularly during the dry season when natural feed resources are limited. Providing targeted supplementation during this period can accelerate growth, improve body condition and increase the likelihood of timely conception. This approach aligns with adaptive selection protocols aimed at optimizing herd productivity under environmental constraints.

4.4 MORPHOMETRIC VARIATION OF REPLACEMENT HEIFERS

The observed body measurements are consistent with previous characterisations of West African zebu cattle [14, 15]. Statistically significant differences ($p < 0.001$) were identified between racial types for chest circumference, live weight and live weight-to-rump height ratio. Heifers with a higher proportion of Afrikaner ancestry exhibited superior body condition, which corroborates earlier findings regarding their somatic development and adaptive potential [3].

However, no significant differences were observed for pelvic width, rump height or skeletal score, which suggests that the influence of breed on morphometric traits is partial and potentially confounded by uncontrolled crossbreeding and environmental variability [16]. The live weight-to-rump height ratio, which was used as a proxy for body condition score (BCS) in this study, is closely associated with reproductive performance and fertility [17]. Afrikaner-type heifers generally have a better BCS, particularly during the rainy season, and demonstrate strong adaptation to low-rainfall savannah environments [18]. Although Brahman-type cattle are known for their robustness, their heavier skeletal structure can result in lower muscle yield and poorer body condition in similar circumstances [3]. These findings support the strategic incorporation of Afrikaner genetics into local herds, even in non-controlled mating systems, to improve body condition and reproductive efficiency in extensive production settings.

The pronounced variability observed in skeletal score (SC) contrasts with the relative stability of other morphometric traits, highlighting its sensitivity to environmental and management practices [5]. This responsiveness suggests that SC may serve as a valuable indicator for refining selection criteria, particularly in systems where nutritional fluctuations are common. However, its utility depends on the confirmation of heritability, which remains to be established.

Selecting heifers that exhibit balanced morphometric development, and an adequate live weight may contribute to improved slaughter outcomes and a reduced incidence of calving complications [19]. However, in the absence of genetic evaluations, such as estimated breeding values (EBVs) or pedigree-based selection indices,

these recommendations remain strictly phenotypic. They should not be interpreted as genetic selection strategies, but rather as operational guidelines for short-term herd management.

The timing of the selection process, conducted early in the rainy season, likely influenced the morphometric measurements of the heifers, as many animals had not yet recovered from weight loss incurred during the preceding dry season. This seasonal effect is well documented in extensive systems where nutritional stress and compensatory growth cycles are commonplace [20]. Furthermore, pasture degradation resulting from reduced herd size and suboptimal grazing conditions has led to grass lignification which further limits nutritional recovery and delays somatic development [21]. Despite a substantial reduction in herd size from 30,000 to 18,000 head across 216,000 hectares, pasture conditions remain inadequate, highlighting the need for strategic feeding interventions and carefully timed selection protocols.

Traditional assessments of sexual maturity in heifers often rely on target weight thresholds [22]. However, this study revealed considerable variation in stature, growth rate and body weight among heifers of the same age group. This highlights the limitations of using uniform selection criteria for heterogeneous populations. To address this, K-means clustering was used to identify three morphometrically homogeneous groups, each centered around a distinct phenotypic profile [8, 23]. While this classification improves the accuracy of management decisions, such as nutritional planning and determining breeding readiness, it is important to emphasize that phenotypic clustering does not equate to genetic selection. Without estimated breeding values (EBVs), pedigree records or genomic data, the approach remains descriptive and operational. Future integration of genetic evaluations will be essential to transition from phenotype-based grouping to evidence-based genetic improvement strategies.

The combined use of skeletal score and percentage of estimated adult weight, as recommended by Troxel and Gadberry (7), was effective in characterising growth trajectories among replacement heifers. While these traits are positively correlated at the phenotypic level, only genetic correlations and heritability estimates, such as those reported for skeletal score (0.40–0.61) by Funston and Deutscher [24], can reliably inform selection decisions. These genetic parameters were not assessed in the present study but should be prioritized in future research to inform genetic improvement based on evidence.

Breed type was not significantly associated with cluster membership ($p > 0.05$), indicating that morphometric variation transcends racial classification. Nevertheless, significant differences in trait averages between most clusters ($p < 0.05$) suggest that each group may benefit from tailored management strategies. The three clusters identified through K-means analysis reflect distinct growth patterns:

Cluster 1: Heifers with intermediate morphology and balanced development (live weight: 349 kg; skeletal score: 4.43), indicative of generalist growth and moderate maturity.

Cluster 2: Large-framed individuals with expansive dimensions (withers height: 136 cm; estimated adult weight: 579 kg; skeletal score: 5.60). However, they have lower maturity indicators (adult weight percentage: 60.9%), suggesting delayed physiological development.

Cluster 3 comprises smaller heifers (live weight: 328 kg), with a higher adult weight percentage (70.6%) and lower skeletal scores. This is consistent with relative precocity and early maturation.

These profiles reveal functional differentiation that is not captured by breed labels alone. Therefore, the use of morphometric clustering offers a practical framework for refining reproductive planning and nutritional management, particularly in systems where pedigree data and genetic evaluations are unavailable.

4.5 PRACTICAL IMPLICATIONS OF MORPHOMETRIC CLASSES OF REPLACEMENT HEIFERS

From an operational standpoint, the three morphometric classes identified in this study provide distinct management approaches for replacement heifers.

- Class 1 includes heifers with average body measurements and skeletal scores ranging from 4 to 6. Notably, 99.1% of these animals met the reproductive eligibility criteria. Their profiles align with Beef Improvement Federation guidelines and reflect the early attainment of optimal adult weight and maturation, as previously described by Patterson et al.
- Class 2 comprises large-framed heifers, 65.8% of which had skeletal scores of at least 6. However, 34.8% had not yet reached the minimum weight required for reproduction. Despite their physical advantages, these animals may require targeted nutritional support to meet reproductive thresholds [19]. Their inclusion in breeding programmes should be guided by long-term productivity objectives rather than size alone.
- Class 3 consists of small-framed heifers with skeletal scores below optimal thresholds yet exhibiting higher adult weight percentages ($70.68 \pm 6.70\%$). These animals demonstrate efficient compensatory growth and, if paired with bulls exhibiting higher skeletal scores ($\geq 6-7$), may be suitable for early reproduction, as suggested by Epstein [25].

These findings underscore the importance of clearly defining selection objectives for replacement heifers [26]. As future genetic contributors to the herd, their management must be tailored to their morphometric profiles

and reproductive potential. In the absence of direct adult weight data, estimates were derived from age, rump height, and skeletal score. This revealed that some of the selected females had not yet reached 60% of their estimated adult weight, which is a commonly accepted threshold for reproductive readiness.

As Stockton et al. [22] emphasize, it is not possible to optimize all replacement heifers using a single maturity index. Morphologically distinct animals may reach comparable maturity levels at different physiological and economic costs, requiring differentiated management strategies. These strategies include monitoring physical condition through live weight and skeletal score, adapting feeding plans to individual growth trajectories and timing reproductive admission based on precocity indicators.

Such approaches are managerial in nature and must not be confused with genetic selection, which requires the evaluation of heritable traits, performance recording and pedigree or genomic data. The present study highlights a key trade-off: smaller-framed heifers typically require fewer resources to reach reproductive maturity, whereas larger-framed animals demand greater nutritional investment. Nevertheless, market preferences and carcass valuation often favor larger animals, justifying strategic adjustments in mating and feeding practices. Operational recommendations based on morphometric classification include:

- Class 3 heifers may be considered for early reproduction if mated with bulls exhibiting higher skeletal scores ($\geq 6-7$), thereby improving the potential of their offspring's carcasses [25].
- Class 2 heifers require sustained nutritional support to avoid reproductive delays and mitigate economic losses [27].
- Class 1 heifers that meet all selection criteria can be admitted to reproduction immediately. Their profiles align with recommendations for cattle adapted to hot, dry environments, and strict selection within this group may enhance herd productivity [28].

Ultimately, morphometric classification provides a practical approach to managing replacement heifers in extensive tropical systems. However, integrating it into genetic improvement programs will require additional data on trait heritability, genetic correlations and economic performance metrics. Future research should prioritize these parameters to transition from descriptive phenotypic management to evidence-based genetic selection.

V. CONCLUSION AND PERSPECTIVES

This study highlights the morphometric and genetic potential of indigenous cattle breeds, particularly Afrikaner-type animals, in contributing to sustainable meat production systems in tropical regions. The observed traits are consistent with previous characterizations, reinforcing the view that local breeds can meet commercial quality standards while retaining their adaptive resilience to harsh environments when properly characterized and managed.

Beyond validating existing potential, the findings necessitate a paradigm shift in the selection and management of replacement heifers. To transition from descriptive phenotypic classification to strategic genetic improvement, future research and development efforts should prioritize the following:

Region-specific morphometric selection protocols that integrate environmental constraints, production goals and local breed characteristics.

Genomic characterization and marker-assisted selection should complement phenotypic assessments and accelerate genetic progress.

Cross-disciplinary approaches combining animal science, socioeconomics and climate resilience are needed to design inclusive, context-aware breeding programs.

Capacity building and data-driven decision-making tools should be developed to empower local stakeholders to implement scientifically grounded selection strategies.

By bridging operational realities with scientific rigor, this work lays the foundation for a more resilient and responsive livestock sector. The outlined perspectives aim to stimulate collaborative efforts across research, education and policy to ensure that indigenous genetic resources are preserved and strategically mobilized for regional development and food security.

Competing interests

No competing interests exist.

Authors' contributions

'Author 1' collected data, and wrote the first draft of the manuscript

'Author 2' and 'Author 3' managed the analyses of the study.

Author 3' led the study, designed the study, wrote the protocol, performed the statistical analysis, managed the literature searches and edited the manuscript. All authors read and approved of the final manuscript.

Ethical approval

The manuscript does not contain clinical studies or patient data.

Disclaimer (artificial intelligence): Author(s) hereby declare that DeepL Write AI was used to improve the writing of the text.

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