Genetic Resources

ORIGINAL ARTICLE

Genetic Resources (2025), 6 (11), 71–81
DOI: 10.46265/genresj.SCLC1551
https://www.genresj.org
ISSN: 2708-3764

Phenotypic characterization of cattle breeds in Southern Ethiopia: Implications for breed differentiation and conservation

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Abstract: This study aimed to characterize and quantify the phenotypic relationship between Gamo and Gofa cattle breeds using nine morphometric measurements and 11 morphological traits. A total of 600 adult cattle (486 females and 114 males) were randomly selected from six purposively chosen districts. Univariate and multivariate analyses were conducted using Statistical Analysis Software. The univariate analysis revealed the morphometric values and morphological characteristics of both cattle breeds but did not show significant variations between them. The majority of the cattle exhibited uniformly patterned coat colour, upward-oriented, straight-shaped horns with black colour, laterally oriented ears with rounded edges, straight face profiles, small hump sizes, short coat hair, and medium tail length. In accordance with the phenotypic similarities observed in the univariate analysis, multivariate analysis also failed to identify significant differences between the two breeds. These results suggest that the two cattle breeds are phenotypically inseparable. However, these phenotypic similarities do not necessarily indicate genetic similarities. Therefore, further genetic characterization is recommended to assess the degree of genetic relationship between the breeds. In the meantime, it is advised to design breed-specific *in situ* conservation and genetic improvement programmes without separating the cattle breeds.

Keywords: Gamo-Gofa, morphological traits, phenotypic characterization, univariate analysis

Citation: Banjaw, B., Didanna, H. L., Mustefa, A. (2025). Phenotypic characterization of cattle breeds in Southern Ethiopia: Implications for breed differentiation and conservation. *Genetic Resources* 6 (11), 71–81. doi: 10.46265/genresj.SCLC1551.

Introduction

Ethiopian indigenous cattle are vital to the livelihoods of smallholder farmers and significantly contribute to the nation's economy, particularly through their role in the agricultural GDP (CSA, 2022). These cattle are primarily valued for milk, meat and draught power, while also serving as sources of income, manure and cultural capital (Zerabruk and Vangen, 2005; Genzebu *et al*, 2012; Yimamu, 2014; Kebede *et al*, 2017; Getachew *et al*, 2020). With an estimated population of 70.3 million cattle, Ethiopia hosts the largest cattle herd in Africa (CSA, 2022; Statista, 2024), underscoring their prominence within the livestock sector.

Genetic diversity, both within and among breeds, is a critical foundation for conservation and genetic improvement strategies. Indigenous breeds dominate Ethiopia's cattle population, comprising 28 officially registered breeds (EBI, 2016; Mustefa, 2023). However, several gaps exist in breeds' documentation and characterization. For instance, several phenotypically studied breeds – including Bonga, Fellata, Gamo and Qocherie – remain unregistered, while others (e.g. Adwa, Hamer and Smada) lack comprehensive phenotypic data despite formal registration (Mustefa, 2023). Addressing these inconsistencies is essential to establish a nationwide framework for breed-specific conservation and genetic improvement programmes.

This study focused on two cattle breeds, Gamo and Gofa. The Gofa cattle breed, which was first studied by Rege and Tawa (1999), is officially registered in the Ethiopian indigenous cattle breeds database (EBI,

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Received: 06.02.2025 | Accepted: 30.04.2025 | Published online: 10.06.2025

2016). Gofa cattle, primarily used for work, milk and meat, were categorized as Small East African Zebu (SEAZ) (Rege, 1999). According to Rege and Tawa (1999), Gofa cattle are one of the smallest strains not only among the Abyssinian zebu but also among all Ethiopian cattle. Small hump, small to medium horns and dominantly red colour are some of their qualitative characteristics (Rege and Tawa, 1999). The study by Kebede *et al* (2017) on Gofa cattle has also reported the existence of diverse coat colours, patterns and qualitative traits. The name Gofa cattle was first introduced by Rege and Tawa (1999) and then by Kebede *et al* (2017) after the 'Gofa' ethnic community which raised them.

On the other hand, Gamo cattle, first studied by Chebo *et al* (2013), were not officially registered in the Ethiopian indigenous cattle breeds database (EBI, 2016). However, the study by Chebo *et al* (2013) showed the existence of potential cattle breeds in the area. According to Chebo *et al* (2013), the Gamo cattle were further divided into two subpopulations: the Gamo Highland and the Gamo Lowland. The Gamo Highland were relatively smaller with compact bodies compared to the medium-to-large-bodied Gamo lowland subpopulations. The name Gamo cattle was first introduced by Chebo *et al* (2013) after the 'Gamo' ethnic community which raised them.

The production system of both Gamo and Gofa cattle breeds was reported to be similar, with cattle owners practising comparable husbandry methods. Own and communal grazing lands were the source of feed, while natural and controlled breeding were the common breeding systems among the owners of both cattle breeds (Chebo *et al*, 2013; Kebede *et al*, 2017; Zeleke *et al*, 2017). However, as mentioned above, the two cattle breeds were studied separately and at different times. This hindered the comparison of the two breeds, which further affected the breed registration as well as the development of breed-specific breeding programmes. Therefore, an inclusive phenotypic characterization study was mandatory to understand the relationships between the breeds. Thus, the current study aimed to conduct an on-farm phenotypic characterization of Gamo and Gofa cattle, assess their morphological diversity, and quantify the degree of phenotypic divergence between them.

Materials and methods

Study areas

The study was carried out in the Gamo and the Gofa zones. Three districts were selected from each zone: Kucha, Daramalo and Dita districts from Gamo zone, as well as Zala, Denbagofa and Oyda districts from Gofa zone (Figure 1). Weather and agroecology-related information of the selected districts are presented in Table 1.

Site and animal selection

Representative samples of Gamo and Gofa cattle breeds were selected from their respective breeding areas. Information on their breeding regions and distribution zones was gathered using secondary sources. The Gamo cattle breed is reported to be native to the Gamo zone, with its distribution extending into the neighbouring Gofa zone (Rege and Tawa, 1999; Chebo *et al*, 2013). Thus, three districts – Kucha, Daramalo and Dita – were randomly chosen from Gamo zone to represent the indigenous Gamo cattle. Similarly, Gofa cattle are reported to be primarily found in Gofa zone, with their distribution reaching into the neighbouring Gamo zone (Rege and Tawa, 1999; Kebede *et al*, 2017). Accordingly, three districts – Zala, Denbagofa, and Oyda – were randomly selected from Gofa zone to represent the indigenous Gofa cattle. From each district, two sampling sites (known as 'Kebeles,' the smallest administrative units) were randomly chosen. Twenty-five households-raising cattle were then randomly selected from each sampling site. From each household, two unrelated adult cattle, aged four years and older, were randomly chosen. One male cattle was sampled every two households within each kebele. These animals were carefully monitored by their owners and trained labourers. Aggressive cattle that were unable to stand properly on flat ground were excluded from measurements.

Data collection

Morphometric and morphological data were collected following the FAO (2012) guidelines. Data collection was conducted in the morning to minimize the effects of feeding and watering on the measurements. Three researchers were involved in the data collection process: two handled the morphometric data, while the third recorded the morphological data. To minimize bias, the same researchers performed the data collection in all sites throughout the study. The animals were measured using a textile measuring tape in centimetres. A total of 600 cattle (486 females and 114 males) were subjected to nine morphometric measurements (Table 2) and 11 qualitative (morphological) traits (Figure 2, Table 3). For data analysis, the cattle were grouped into three age categories based on the classification by Tatum (2011): group one (3–5 years), group two (6–7 years) and group three (8 years and older).

Data analysis

The overall data analysis was carried out using the Statistical Analysis System (SAS) software 9.0 (SAS, 2002).

UNIVARIATE procedure for data normality test, the frequency procedure for morphological (qualitative) data analysis, and the general linear model (GLM) procedure for morphometric (quantitative) data analysis were used. Data analysis was carried out using the following model: $Y_{ijk} = \mu + X_i + Y_j + Z_k + e_{ijk}$ where

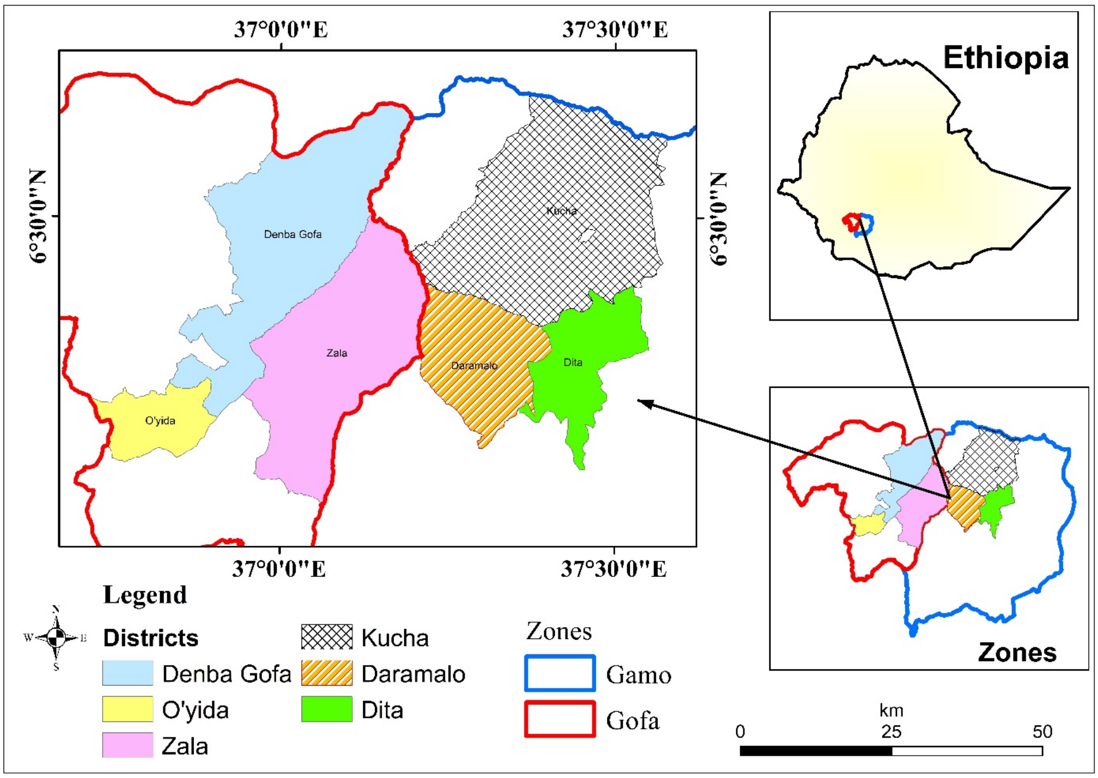

Figure 1. Map of the studied areas

Table 1. Weather and agroecology-related information of the selected districts (Gegnaw and Hadado, 2014; Leulalem *et al*, 2016; Kebede *et al*, 2017; Cholo *et al*, 2018; Chankalo, 2022; CSA, 2022; Kassa *et al*, 2022).

Parameters	Gamo zone			Gofa zone		
	Kucha	Daramalo	Dita	Zala	Dembagofa	Oyda
Human population	163,832	110,815	111,283	105,949	114,382	51,784
Cattle population	211,574	219,452	157,300	303,095	289,097	121,431
Temperature (°C)	20–25	19–22	10–23	18–32	18–28	15–25
Rain fall (mm)	1,100–1,600	1,300–1,900	2,500–3,500	500–900	900–1,100	1,000–2,000
Altitude	800–2,250	1,217–2,700	1,800–3,500	1,194–1,484	800– 2,860	1,000–3,200
Agroecology (%)						
Lowland	49.4	29.2	-	90	75	27
Midland	50.6	33.3	40	10	15	40
Highland	-	37.5	60	-	10	33

Table 2. Listof morphometric traits with their respective definitions. Measurements were conducted in centimetres (FAO, 2012).

No.	Morphometric traits	Definitions
1	Body length	Distance from shoulder point to pin bone
2	Heart girth	Chest circumference right behind its front two legs
3	Height at withers	Distance from ground to withers of the front foot
4	Pelvic width	Distance between the two ends of the pelvic bone
5	Muzzle circumference	Perimeter of the mouth
6	Ear length	Distance from the root to the tip of the back side of the ear
7	Horn length	Outer side distance between root and tip of the horn
8	Cannon bone length	Distance between the fetlock joint (ankle) and the knee
9	Hock circumference	Perimeter of the hock bone

Y_{ijk} is an observation, μ is the overall mean, X_i is the fixed effect of breed (i = Gamo, Gofa), Y_j is the fixed effect of sex (j = male, female), Z_k is the fixed effect of age (k = 3–5, 6–7, ≥8 years) and e_{ijk} is the random error. However, the effect of age on all qualitative traits was found to be not significant; hence, it is omitted from the model. Additionally, the quantitative data were analyzed separately for each sex by fitting breed as a class variable. Means (LSM) were separated using the adjusted Tukey-Kramer (Tukey, 1953; Kramer, 1956).

Multivariate analysis was carried out separately for each sex using both the morphometric and morphological traits at the same time. Prior to the analysis, the morphological traits were coded using discrete values. Stepwise discriminant analysis to detect morphometric traits that could better classify the cattle breeds, discriminant analysis to allocate individuals to known breeds and assess possibilities of misclassifications, and canonical discriminant analysis to deliver maximal separations between breeds were used. Graphic interpretation of breed differences was plotted using the scored canonical variables. Pairwise Mahalanobis distances between breeds were computed as $D^2\left(i|j\right) = \left(x_i - x_j\right)' cov^{-1}\ \left(x_i - x_j\right)$. Where $D^2\left(i|j\right)$ is the distance between breeds i and j, cov^{-1} is the inverse of the covariance matrix of measured variables, x_i and x_j are the means of variables in the i^{th} and j^{th} breeds.

Results

Qualitative characteristics

The coat colour of the two studied breeds and sexes is presented in Figure 2. The coat colour was not significantly affected by breed, but it was affected by their sex. The majority of the studied cattle possessed red and light red coat colour. Sex-wise results revealed a high proportion of red-coloured females, while males possessed a light-red coat colour.

The effect of breed and sex on the qualitative characteristics of Gamo and Gofa cattle breeds is presented in Table 3 along with the respective chi-square values and levels of significance. Relatively, breed affected more morphological traits than sex: three out of the ten morphological traits were affected significantly by the breed of the animals, while sex affected only one trait. Accordingly, the majority of the studied cattle populations possessed uniformly-patterned coat colour, upward-oriented straight-shaped horns with black colour, laterally-oriented round edge ears, straight face profile, small hump size, short coat hair size, and medium tail length.

Morphometric traits

Tables 4 and 5 present the least square means, standard errors and pairwise comparisons showing the effect of breed, sex and age on the morphometric traits of the studied cattle populations. Breed affected two out of the nine morphometric traits, with Gofa cattle exhibiting greater pelvic width and horn length measurements compared to Gamo cattle. However, the effect of breed on the morphometric measurements was found to be sex-dependent. Breed significantly affected pelvic width and horn length measurements of the females, with values higher in Gofa females. However, these measurements of the male cattle populations were not significantly affected by breed differences. On the other hand, the heart girth measurement of the males was significantly affected by breed, with Gamo males having higher measurements than their counterparts from Gofa. However, the heart girth measurement of the females was not significantly affected by breed.

Similarly, sex affected seven out of the nine morphometric traits, with males exhibiting larger measurements than females in most of the traits except for ear and horn length. Age affected five of the nine morphometric traits, with most measurements increasing as the animal grew older. Body length and heart girth measurements were found to be stable after the age of six years. However, muzzle circumference and horn length measurements of middle-aged animals were found to be the highest among the compared age groups.

Multivariate analysis

Stepwise discriminant analysis

Ten out of the 20 morphometric and morphological traits were used to discriminate the female cattle populations while six traits were used to discriminate the males. The three most important morphometric variables used in discriminating the cattle breeds were horn length, pelvic width and coat colour pattern among females, and horn shape and horn length among males (Table 6). The overall results show the existence of low partial R-Square and F-values.

Discriminant analysis

Results of the discriminant analysis showed moderate classification of individual animals into their corresponding breed (Table 7). The highest classification into their respective breed was observed in Gamo males, while the lowest classification was observed in Gofa females.

Canonical discriminant analysis

Canonical correlations and eigenvalues for both male and female cattle populations are shown in Table 8. In line with the low partial R-Square and F-value outputs in Table 6, the eigenvalues were also small enough to discriminate between the two cattle breeds in both sexes. However, relatively higher Eigenvalues were observed for males than females. Similarly, the canonical correlation, which was used to build the canonical variate 1 (Can 1) from the used traits, was also low. However, a relatively higher canonical correlation was observed for males than females.

Pairwise squared Mahalanobis distances between the breeds were calculated as 1.43 for females and

Table 3. Percentages of qualitative characteristics of cattle populations by sex and breed.

Qualitative traits		Cattle Breed				Sex			
		Gamo (300)	Gofa (300)	χ^2 value	P	Males (114)	Females (486)	χ^2 value	P
Coat colour pattern	Uniform	85.3	78.0	5.4	NS	82.5	81.5	0.27	NS
	Patchy	9.7	14.0			10.5	12.1		
	Spotted	5.0	8.0			7.0	6.4		
Horn shape	Straight	69.3	59.0	7.0	**	65.8	63.8	0.16	NS
	Curved	30.7	41.0			34.2	36.2		
Horn orientation	Lateral	8.7	14.7	7.3	NS	15.8	10.7	13.2	*
	Upward	69.7	68.7			63.2	70.6		
	Downward	10.0	7.7			14.0	7.6		
	Forward	10.0	8.3			4.4	10.3		
	Backward	1.6	0.6			2.6	0.8		
Horn colour	Black	59.3	59.3	5.2	NS	50.9	60.7	4.6	NS
	Brown	9.0	6.3			9.6	7.2		
	White	28.0	33.7			35.1	29.8		
	Black + white	3.7	1.7			4.4	2.3		
Ear shape	Round edged	93.0	94.7	0.72	NS	91.2	94.4	1.7	NS
	Straight edged	7.0	5.3			8.8	5.6		
Ear orientation	Erect	16.3	20.0	10.5	**	18.4	18.1	2.0	NS
	Lateral	78.7	68.7			70.2	74.5		
	Dropping	5.0	11.3			11.4	7.4		
Face profile	Straight	83.7	90.7	7.0	*	89.5	86.6	1.5	NS
	Concave	13.0	8.0			9.6	10.7		
	Convex	3.3	1.3			0.9	2.7		
Hump size	Absent	5.3	3.3	2.7	NS	7.9	3.5	0.27	NS
	Small	61.3	59.7			54.4	61.9		
	Medium	32.3	35.0			35.1	33.3		
	Large	1.1	2.0			2.6	1.3		
Coat hair length	Short	93.7	94.0	0.03	NS	93.9	93.8	1.6	NS
	Medium	5.3	5.0			6.1	5.0		
	Long	1.0	1.0			0	1.2		
Tail length	Short	4.3	6.0	0.86	NS	2.6	5.8	1.9	NS
	Medium	74.0	73.0			76.3	72.8		
	Long	21.7	21.0			21.1	21.4		

Table 4. The effect of breed on the cattle morphometric measurements by sex. Measurements are in centimetres. N, number of animals sampled; BL, Body length; HG, Heart girth; HW, Height at withers; PW, Pelvic width; MC, Muzzle circumference; EL, Ear length; HL, Horn length; CBL, Cannon bone length; HC, Hock circumference; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.0001$; NS, Not significant.

Traits	Aggregate sex			Females			Males		
	Gamo	Gofa	Sig.	Gamo	Gofa	Sig.	Gamo	Gofa	Sig.
N	300	300		249	237		51	63	
BL	109.1±0.37	109.4±0.35	NS	106.9±0.33	107.3±0.34	NS	111.4±0.87	111.1±0.81	NS
HG	137.3±0.40	137.1±0.39	NS	134.1±0.36	135.4±0.37	NS	142.9±0.86	136.0±0.80	***
HW	108.9±0.43	108.8±0.41	NS	106.2±0.38	106.2±0.39	NS	112.2±1.13	111.4±1.05	NS
PW	31.3±0.21	32.9±0.21	***	30.7±0.18	32.4±0.18	***	32.0±0.61	33.0±0.57	NS
MC	36.9±0.15	36.8±0.14	NS	36.4±0.14	36.3±0.14	NS	37.2±0.34	37.1±0.31	NS
EL	17.0±0.11	17.3±0.11	NS	17.3±0.10	17.7±0.11	NS	16.9±0.22	16.6±0.20	NS
HL	16.5±0.21	19.0±0.21	***	17.2±0.20	20.1±0.20	***	16.6±0.41	17.6±0.38	NS
CBL	25.8±0.15	25.7±0.14	NS	25.7±0.14	25.6±0.14	NS	25.7±0.31	25.8±0.29	NS
HC	30.4±0.17	30.6±0.17	NS	30.2±0.16	30.4±0.17	NS	30.8±0.37	30.9±0.35	NS

Table 5. The effect of sex and age on the cattle morphometric measurements. Measurements are in centimetres. N, number of animals sampled; BL, Body length; HG, Heart girth; HW, Height at withers; PW, Pelvic width; MC, Muzzle circumference; EL, Ear length; HL, Horn length; CBL, Cannon bone length; HC, Hock circumference; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.0001$; NS, Not significant.

Traits	Sex			Age			
	Males	Females	Sig.	< 6	6–7	> 7	Sig.
N	114	486		169	234	197	
BL	111.3±0.51	107.1±0.25	***	107.8±0.44^b	109.7±0.38^a	110.1±0.45^a	**
HG	139.6±0.56	134.8±0.27	***	135.9±0.48^b	137.8±0.42^a	137.8±0.50^a	**
HW	111.4±0.60	106.3±0.29	***	107.5±0.51^b	108.7±0.45^b	110.4±0.53^a	***
PW	32.6±0.30	31.6±0.14	**	31.7±0.26	32.4±0.22	32.3±0.26	NS
MC	37.3±0.21	36.3±0.10	***	36.3±0.17^b	37.4±0.15^a	36.7±0.18^b	***
EL	16.9±0.15	17.5±0.07	**	17.2±0.13	17.1±0.12	17.2±0.14	NS
HL	16.9±0.30	18.6±0.14	***	16.4±0.26^c	19.0±0.22^a	17.8±0.26^b	***
CBL	25.9±0.20	25.7±0.10	NS	25.7±0.17	25.9±0.15	25.7±0.18	NS
HC	30.7±0.24	30.2±0.12	NS	30.5±0.21	30.4±0.18	30.5±0.21	NS

Table 6. Order of traits used in discriminating between the two cattle populations using a stepwise discriminant analysis (STEPDISC).

Sex	Step	Variables entered	Partial R-Square	F value	Pr > F	Wilks' Lambda	Pr < Lambda
Females	1	Horn length	0.1630	94.25	< 0.0001	0.8370	< 0.0001
	2	Pelvic width	0.0522	26.60	< 0.0001	0.7933	< 0.0001
	3	Coat colour pattern	0.0121	5.91	0.0154	0.7837	< 0.0001
	4	Canon bone length	0.0099	4.79	0.0291	0.7760	< 0.0001
	5	Face profile	0.0085	4.12	0.0428	0.7694	< 0.0001
	6	Body length	0.0096	4.63	0.0319	0.7620	< 0.0001
	7	Horn shape	0.0076	3.64	0.0570	0.7562	< 0.0001
	8	Muzzle circumference	0.0074	3.55	0.0600	0.7506	< 0.0001
	9	Hair length	0.0065	3.10	0.0792	0.7458	< 0.0001
	10	Horn orientation	0.0047	2.22	0.1368	0.7423	< 0.0001
Males	1	Heart girth	0.2461	35.25	< 0.0001	0.7539	< 0.0001
	2	Horn shape	0.1164	14.10	0.0003	0.6661	< 0.0001
	3	Horn length	0.0585	6.58	0.0117	0.6272	< 0.0001
	4	Hump size	0.0497	5.49	0.0210	0.5960	< 0.0001
	5	Pelvic width	0.0388	4.19	0.0431	0.5729	< 0.0001
	6	Hock circumference	0.0315	3.35	0.0701	0.5548	< 0.0001

Table 7. Number and (percentage) of observations classified into breed.

Sex	Breed	Gamo	Gofa	Total
Females	Gamo	**187 (75.10)**	62 (24.90)	249 (100)
	Gofa	80 (33.76)	**157 (66.24)**	237 (100)
	Error rate	0.2490	0.3376	**0.2933**
Males	Gamo	**43 (86.00)**	7 (14.00)	50 (100)
	Gofa	16 (26.67)	**44 (73.33)**	60 (100)
	Error rate	0.1400	0.2667	**0.2033**

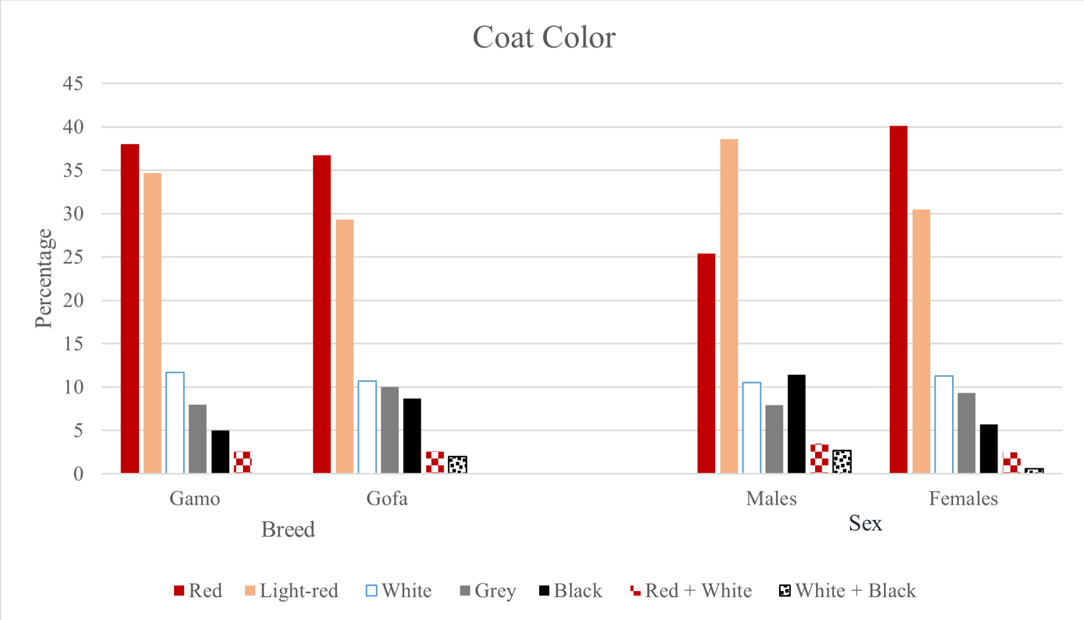

Figure 2. Effect of breed on coat colour (chi-square value 11.2, p = 0.0836), and effect of sex on coat colour (chi-square value 15.9, p = 0.0142).

3.68 for male cattle, indicating that males were more distantly related than females. However, both distances were small and insufficient to indicate a significant distance between the breeds. The overall multivariate analysis results showed low and non-significant distances between Gamo and Gofa cattle breeds.

Plots of the first two canonical variables to discriminate the cattle breeds are presented in Figure 3. In line with the result of the Mahalanobis distances, the studied Gamo and Gofa breeds were found to be inseparable and categorized in the same group, while a relative separation was observed between the males.

Discussion

Qualitative characteristics

Qualitative traits, due to their easily observable nature, are valuable for distinguishing between cattle breeds. Coat colour and coat colour patterns are among the most easily observed traits used to differentiate breeds. However, in this study, these traits did not distinguish the Gamo and Gofa cattle breeds, as most animals from both breeds exhibited uniformly patterned red and light red coat colours. The similarities in coat colour and pattern, along with other morphological and morphometric similarities between the breeds, may suggest genetic relatedness (Mustefa *et al* (2021) for Raya cattle; Getachew *et al* (2014) and Mustefa *et al* (2023) for Ogaden cattle). Therefore, the observed similarities in coat colour and pattern between Gamo and Gofa cattle imply phenotypic resemblance, which may reflect underlying genetic similarities. These findings, however, should be validated through genetic analysis.

The red-dominant coat colour observed in this study aligns with the findings of Rege and Tawa (1999), who identified red as the primary coat colour in Gofa cattle. Similarly, Kebede *et al* (2017) also reported that red and white were the most common coat colours in Gofa cattle. In agreement with these findings, Chebo *et al* (2013) reported that dark and light red were the predominant coat colours in Gamo cattle. The farmers' preference for red coat colour in both breeds may be linked to farmers' selection criteria, as red is a preferred colour in the studied areas. According to Kebede *et al* (2017), coat colour was a significant selection criterion for farmers, following milk yield.

Similarities in other qualitative traits, such as horn, ear, hump, face, hair, and tail lengths, were also observed between the Gamo and Gofa cattle breeds, which challenges their classification as distinct breeds. The minor differences observed could be attributed to variations within the breeds. Such intra-breed variations across different sampling locations were also reported by Terefe *et al* (2015) in Mursi cattle, Mustefa *et al* (2021) in Raya cattle, and Mustefa (2023) in Harar cattle.

Table 8. Multivariate statistics outputs of the canonical structures.

Multivariate Statistics	Females	Males
Canonical correlation	0.5140	0.7087
Eigen value	**0.3591**	**0.9060**

Morphometric traits

Morphometric measurements, in conjunction with qualitative traits, provide reliable information for assessing the degree of relationship between breeds. Most of the

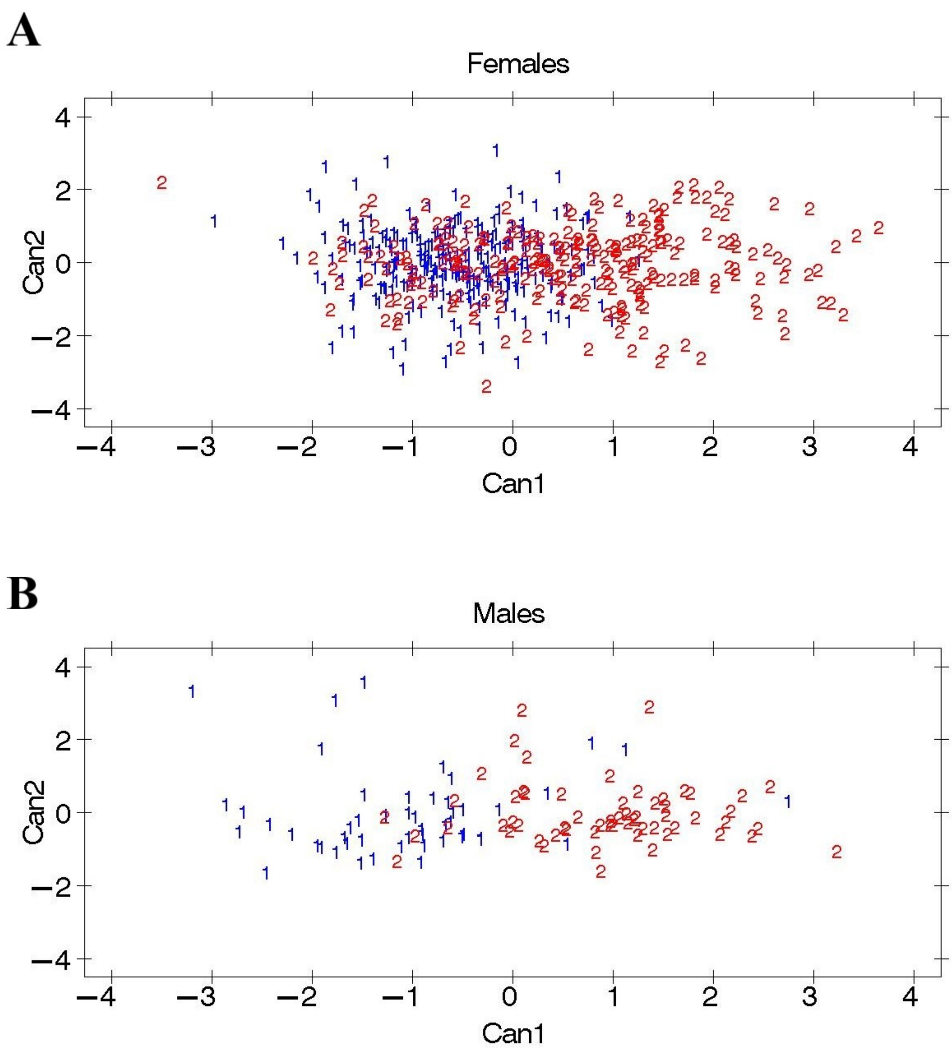

Figure 3. Plots of canonical discriminant analysis based on morphometric traits. A, females; B, males. Breed is indicated by numbers: 1, Gamo; 2, Gofa.

morphometric measurements were similar between the two cattle breeds, which supports the observed qualitative similarities. Consequently, no significant differences were found between the Gamo and Gofa cattle breeds that could serve to differentiate them. As mentioned in the qualitative section, the slight differences observed may reflect within-breed variations. These variations are crucial for designing conservation and genetic improvement programmes. Terefe *et al* (2015) in Mursi cattle, Mustefa *et al* (2021) in Raya cattle, and Mustefa (2023) in Harar cattle also reported morphometric variations within the same breed across different locations.

In comparison with the previous study on Gofa cattle by Kebede *et al* (2017), the Gofa females in this study showed similar body length, heart girth and wither height. However, they had larger muzzle and hock circumferences, and lower ear and horn lengths. In contrast, the Gofa males in this study exhibited comparable body length but lower values for other morphometric measurements. These findings suggest a reduction in body size of Gofa males over the past seven years, possibly due to negative selection practices by farmers. Similarly, most of the morphometric measurements for the cattle breeds in this study were lower than those reported by Chebo *et al* (2013) for Gamo cattle, but comparable to those reported by Zeleke *et al* (2017).

The Gamo and Gofa cattle breeds were found to be smaller than many other Ethiopian indigenous cattle breeds. This observation is consistent with Rege and Tawa (1999) description of Gofa cattle as the smallest strain of Ethiopian cattle. Their morphometric measurements were smaller than those of breeds such as Afar (Tadesse *et al*, 2008), Begait (Ftiwi, 2015), Begaria (Getachew *et al*, 2020), Fogera (Girma *et al*, 2016), Gojjam Highland (Getachew and Ayalew, 2014), Harar (Mustefa, 2023), Kereyu (Nigatu and Tadesse, 2020), Mursi (Terefe *et al*, 2015), Nuer (Minuye *et al*, 2018), Ogaden (Mustefa, 2023) and Raya cattle (Mustefa *et al*, 2021). However, their measurements were larger than those of Abergelle and Irob cattle breeds (Zegeye *et al*, 2021). Similar morphometric traits were also observed in Arado (Genzebu *et al*, 2012) and Horro cattle (Bekele, 2015).

Multivariate analysis

High partial R-Square and F-values are necessary to demonstrate significant discrimination between populations. Additionally, low error rates are essential to show the distinctiveness of separate breeds. However, the results from the stepwise analysis (Table 6) exhibited low partial R-Square and F-values, indicating weak discriminatory potential of the morphometric traits. Furthermore, high error rates (Table 7) were observed, indicating greater similarities between the cattle populations, which lowers the likelihood of classifying the breeds into separate clusters. In contrast, lower error rates would indicate distinct differences between the breeds. For example, an error rate of 1% was reported in the classification of phenotypically unrelated Harar and Ogaden cattle breeds (Mustefa, 2023).

An eigenvalue greater than 1 is required for breed discrimination. If the value falls below 1, discrimination between the studied animals is not significant. The lowest eigenvalues observed in both sexes (Table 8) failed to distinguish the cattle populations into separate clusters, suggesting the absence of two distinct breeds. Similarly, high Mahalanobis distances between breeds are needed for clear cluster separation, but the Mahalanobis distance results in this study were low, with males showing slightly higher distances. This could be attributed to the smaller sample size of oxen. The accuracy of the analysis improves with larger sample sizes. Due to the low eigenvalue (< 1) and short Mahalanobis distances in the multivariate analysis, the studied cattle breeds were found to be phenotypically inseparable. However, phenotypic similarities do not necessarily imply genetic similarities between breeds (Zechner *et al*, 2001).

Effect of sex and age

Sex and age had minimal effects on the qualitative traits of the studied cattle populations since qualitative traits are typically controlled by fewer genes (Falconer, 1989). Therefore, successive planned selection activities are required to bring changes to the qualitative traits. On the other hand, the morphometric traits were influenced by both sex and age, because quantitative traits are influenced by a greater number of genes (Falconer, 1989). This means a few natural or artificial selection activities can produce significant changes to the quantitative traits.

Accordingly, males were generally larger than females in most morphometric traits of both breeds, aligning with Rensch's rule (Rensch, 1950), which suggests that females of a species are usually smaller than males. These differences could be attributed to testosterone, which promotes the development of skeletal and muscle mass in males (Baneh and Hafezian, 2009). The effect of the endocrine system on growth was also significant, with estrogen's influence on growth being more limited in females (Chriha and Ghadri, 2001; Baneh and Hafezian, 2009). Similar findings, showing male dominance in size, were reported by Mustefa (2023) for Harar and Ogaden cattle breeds, Mustefa *et al* (2021) for Raya cattle, and Terefe *et al* (2015) for Mursi cattle.

Age significantly affected five morphometric traits. Body length and heart girth measurements showed stable body development from the middle-aged group, while muzzle circumference and horn length measurements indicated the middle-aged group as optimal for these traits.

Significantly different breeds need to be registered separately, while the same breed should be registered only once. This is because our next step as a country is to design breeding programmes that include both conservation and genetic improvement activities for each breed individually. Therefore, conducting these programmes separately for breeds without significant differences would be inappropriate. The currently observed differences among these breeds can be considered as within-breed variation; however, this needs to be supported by further genetic characterization studies.

Conclusion

In accordance to the observed similarities in morphological and morphometric traits between Gamo and Gofa cattle breeds, multivariate analysis failed to identify significant differences, suggesting that the two breeds are inseparable. However, phenotypic similarities do not necessarily indicate genetic similarity. Therefore, further genetic characterization is recommended to assess the genetic relationship between these breeds. In the meantime, the studied cattle populations should not be regarded as separate breeds. Breed-specific *in situ* conservation and genetic improvement programmes should consider the cattle populations as a single entity. Additionally, a unified breed name that can represent both populations is recommended for consideration by the country's National Advisory Steering Committee for Animal Genetic Resources.

Acknowledgments

The authors are highly indebted to the Ethiopian Biodiversity Institute (EBI) and Wolita Sodo University for covering some of the budget for this work. Our special appreciation also goes to the smallholder farmers/breeders for providing their animals to this work for free. We also take this opportunity to thank the animal science experts and development agents for their endless help during data collection.

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