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Quantifying phenotypic relationships among Arsi, Bale and Jemjem cattle breeds of Ethiopia

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Abstract: Nine morphometric and 16 morphological traits were used to characterize and quantify phenotypic relationships among Arsi, Bale and Jemjem cattle breeds. A total of 441 randomly selected adult cattle (342 females and 99 males) from three purposively selected districts were used. Univariate and multivariate analysis procedures of statistical analysis software (SAS) were used to analyze the data. Clear morphological and morphometric variations were not observed among the cattle breeds. The majority of the studied cattle possessed uniform coat colour pattern (78%), black coat colour (61%), forward-oriented horns (65.8%), widely spaced horns (71.4%) and curved horns (76%). They mostly had erected humps (96.2%), small humps (66.7), mainly located at the cervicothoracic position (77.8%) with a straight face (100%) and back profile (92%) while their rump was sloppy (100%). Overall, 44.4% and 45.6% were medium- and long-tailed, respectively, while most (72.1%) of the cattle possessed medium dewlap width. Most (57.6%) of the males had medium perpetual sheaths while naval flap was not observed on most (53.2%) of their female counterparts. In addition to the univariate analysis, the multivariate analysis also failed to show significant separation among the breeds, as indicated by the short Mahalanobis distances and low eigenvalues. In conclusion, Arsi, Bale and Jemjem cattle breeds were found to be phenotypically inseparable. However, the observed phenotypic similarities among these breeds do not necessarily mean that these cattle breeds are genetically the same. Therefore, further molecular characterization is recommended to quantify the degree of genetic relationships among the studied breeds.

Keywords: Cattle, characterization, Ethiopia, indigenous breeds, morphology, morphometric, multivariate analysis

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Introduction

Ethiopian indigenous cattle genetic resources contribute significantly both to farmers' livelihoods and the country's gross domestic product (GDP) (CSA, 2021). Cattle in Ethiopia are primarily used for milk, meat and drought power. Moreover, they are a source of income and manure, as well as provide social and cultural values (Zerabruk and Vangen, 2005; Genzebu *et al*, 2012; Yimamu, 2014; Kebede *et al*, 2017; Getachew *et al*, 2020). Ethiopia has about 70.3 million heads of cattle (CSA, 2021), making them the most populous livestock species in the country. Furthermore, according to Statista (2020), Ethiopia has the largest cattle population in Africa.

To ensure that cattle production contributes sustainably to the country's food and nutrition security, proper management of the diversity of indigenous breeds is essential (FAO, 2007). To achieve this goal, Ethiopia has adopted the Global Plan of Action (GPA) for Animal Genetic Resources which has four strategic priority areas (SPAs) and 23 strategic priorities (SP) (EBI, 2016). The first SPA – characterization, inventory and risk monitoring – aims to produce sufficient and accurate information for enhanced management of animal genetic resources (AnGR). Outputs from this SPA include knowledge of the genetic diversity, population structure

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and population differentiation of indigenous breeds. To achieve these outputs, phenotypic and genetic characterization studies are required (FAO, 2012; Ajmone-Marsan *et al*, 2023).

Several cattle phenotypic and genetic characterization studies have been carried out in Ethiopia in the past three decades, leading to the registration of 28 indigenous breeds (EBI, 2016; Mustefa, 2023). The phenotypic characterization studies provided a list of the breeds believed to exist in the country, the breeds' distribution areas and characteristics, and their linear body measurements. Similarly, molecular characterization studies assessed the within- and among-breed genetic diversity and differentiation. However, the phenotypic and molecular characterization studies carried out so far have not been comprehensive, particularly in terms of breed differentiation and registration. The phenotypic studies were limited by narrow geographic coverage, inconsistent naming and varying methodologies. Molecular studies were contradictory, and showed discrepancies between phenotypic characteristics and geographical distances among the breeds (Mustefa, 2023). Moreover, some cattle breeds including Adwa, Ambo, Bale, Hamer, Jemjem, Jigjiga, and Smada were registered without adequate phenotypic characterization studies. Addressing these gaps is essential to provide a complete and country-wide picture, which in turn will inform the design of breed-specific genetic improvement and conservation programmes.

The current study targeted three registered cattle breeds: The Arsi, Bale, and Jemjem (EBI, 2016; Assefa and Hailu, 2018). Two of them, Bale and Jemjem, were not studied before while Arsi was studied by Yimamu (2014), which revealed some of the unique characteristics and distribution areas of this cattle. The breed has a compact body with a uniformly patterned black coat colour. It is reported to have originated in the Arsi highlands, with a distribution up to Bale and Sidama highlands (Assefa and Hailu, 2018). These zones were also identified as the home to other cattle breeds: Bale highland is the breeding tract of Bale cattle (Assefa and Hailu, 2018), and Sidama highland is the breeding tract of Jemjem (Sidama highland) cattle (Assefa and Hailu, 2018; Legesse and Zeleke, 2021).

The study by Legesse and Zeleke (2021) on Sidama highland cattle showed some phenotypic resemblances with Arsi. Furthermore, Legesse and Zeleke (2021) reported the neighbouring Arsi and Bale highland areas as the origin of Sidama highland cattle. Therefore, the breeds that exist in the Arsi, Bale, and Sidama highlands seem to be the same breeds with different names. Therefore, an inclusive study taking representative samples from these areas is required to quantify the level of relationships among these breeds. The current study aimed to phenotypically characterize Arsi, Bale, and Jemjem cattle breeds and quantify the level of phenotypic relationships using multivariate analysis.

Materials and methods

Study areas

The study was conducted in two regions, Oromia and Sidama. Three districts – Diksis district of Arsi zone and Goba district of Bale zone in Oromia, and Hula district in Sidama (Figure 1) – were covered. Some parameters of the sampled districts including weather conditions and agroecology are presented in Table 1.

Site and animal selection

Representative samples of Arsi, Bale and Jemjem cattle breeds were selected from their respective breeding tract. Information on their breeding tract and distribution areas were identified from previous studies (Rege and Tawa, 1999; Yimamu, 2014; Assefa and Hailu, 2018; Legesse and Zeleke, 2021). Accordingly, Diksis district was randomly selected from the highland districts of the Arsi zone to represent Arsi cattle, Goba district was randomly selected from the highland districts of the Bale zone to represent Bale cattle, while Hula district was randomly selected from the highland districts of the Sidama region to represent Jemjem cattle. Two sampling sites (Kebeles) were randomly selected from each district. Forty households that reared cattle were randomly selected from each sampling site (kebele). Within each household, the adult cattle aged four years and above were first separated from the young ones to avoid age bias. Genetically unrelated animals were separated to make the sampling representative. Then, two animals were selected randomly for the morphometric and morphological recording to avoid sampling bias. Selected animals were controlled carefully by their owners and trained labourers. Aggressive animals that could not properly stand on the flat ground were not recorded to avoid measurement bias.

Data collection

Data on morphometric (quantitative linear body measurements) and morphological (qualitative characteristics) traits were collected based on the data collection procedures described in the UN's Food and Agriculture Organization (FAO) guidelines (FAO, 2012). Data collection was performed in the morning to avoid errors regarding feeding and watering. Five researchers were involved in the data collection procedure: three handled the quantitative data while the remaining two took care of the qualitative data decision-making and recording. To reduce bias, morphometric data recording was performed by the same researcher throughout the study. Animals were measured using a centimeter-unit textile measurement tape. A total of 441 cattle (342 females and 99 males) were subjected to nine morphometric measurements (Table 2) and 16 morphological/qualitative traits (Table 3).

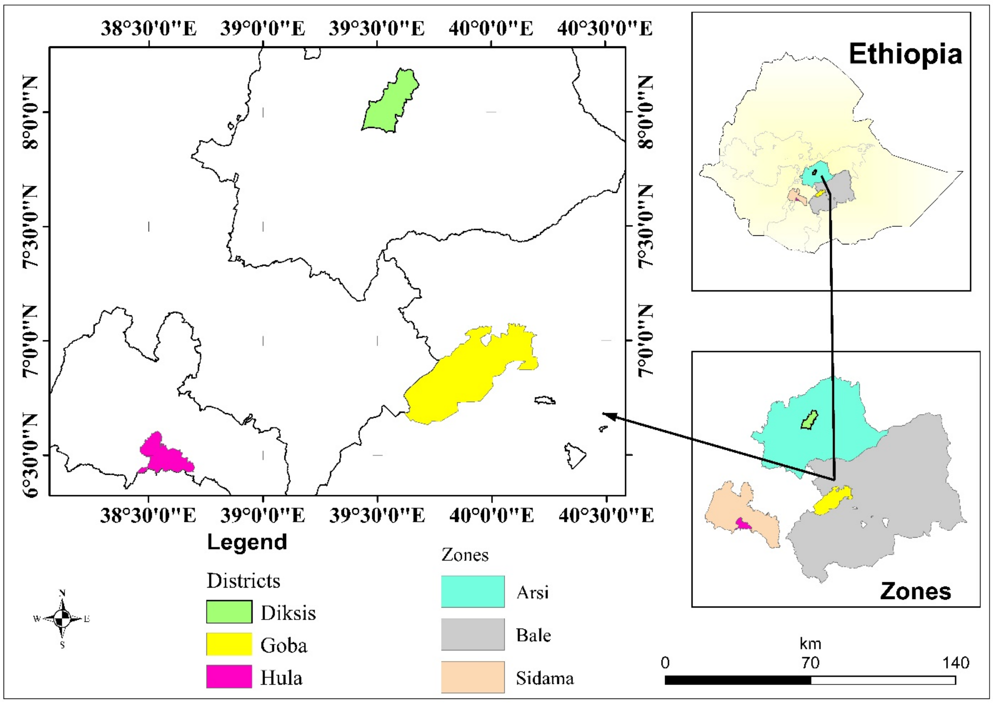

Figure 1. Map of the study areas

Table 1. Weather and agroecology-related information of the selected districts. Source: (Yimamu, 2014; Tiki *et al*, 2016; Teshale *et al*, 2017).

Parameters	Districts		
	Diksis	**Goba**	**Hula**
Altitude of the district (m.a.s.l.)	2,200–2,800	1,500–4,377	1,501–3,500
Altitude of the sampled locations (m.a.s.l.)	2,710–2,721	2,588–2,596	2,709–2,718
Temperature (°C)	18	0–23	12–22.5
Rainfall (mm)	700–1,300	1,033–1,112	1,200–1,600
Area (km^2)	283	-	270
Cattle population	139,568	-	124,472
Human population	215,337	165,712	161,214
Ethnicity	Oromo	Oromo	Sidama

Table 2. List of the linear body measurements with their definitions. These measurements were carried out using a centimetre (cm) unit measuring tape. Source: FAO (2012).

No.	Morphometric traits	Definitions
1	Body length	Distance from shoulder point to pin bone
2	Heart girth	Chest circumference right behind the two front 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

Data analysis

A Microsoft Office Excel worksheet was used to enter and manage data, while the overall data analysis was carried out using various procedures of the Statistical Analysis System (SAS) software 9.0 (SAS, 2002).

Univariate analysis

UNIVARIATE procedure of SAS (SAS, 2002) was used for data normality test, the frequency procedure (Chi-square test) was used for morphological (qualitative) data analysis, and the general linear model (GLM) procedure was used for morphometric (quantitative) data analysis. The following statistical analysis model was used to analyze the morphological data:

$Y_{ij} = \mu + S_i + B_j + e_{ij}$

where Y_{ij} is an observation, μ is the overall mean, S_i is the fixed effect of sex (i = male, female), B_j is the fixed effect of breed (j = Arsi, Bale, Jemjem) and e_{ij} is the random error. Quantitative data were analyzed separately for each sex by fitting breed as a class variable. Means (LSM) were separated using the adjusted Tukey-Kramer test (Tukey, 1953; Kramer, 1956).

Multivariate analysis

Stepwise discriminant analysis (SAS, 2016) was used to detect morphometric traits that better discriminate the cattle breeds, while discriminant analysis was applied to allocate individuals to known breeds and assess possibilities of misclassifications. Canonical discriminant analysis was also employed to deliver maximal separations between breeds (SAS, 2002). Graphic interpretation of breed differences was plotted using the scored canonical variables. Pairwise Mahalanobis distances between breeds were computed as $D^2\,(i|j) = (x_i - x_j)^{'}\,cov^{-1}\,(x_i - x_j)$. Where $D^2\,(i|j)$ 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

Figure 2 shows the coat colour distribution across the two sexes and three breeds studied. While coat colour was not significantly influenced by the animals' sex (chi-square value 4.5, p = 0.3480), it did vary by breed (chi-square value 37.9, p < 0.0001). Black coat colour was predominant across all three breeds, while black + white coat animals were observed more frequently in Jemjem cattle. Black + white coloured animals are those with predominantly black coat colour with some white patches, spots or shades. Their coat colour pattern can be also indicated as pied, spotty or shaded. The same applied to the red + white coloured animals.

The effects of breed and sex on the qualitative characteristics of Arsi, Bale and Jemjem breeds are presented in Table 3 along with the respective chi-square values and levels of significance. Sex affected 6 out of the 13 traits while breed significantly affected 7 out of the 15 traits. The majority of the studied cattle had forward-oriented (65.8%), widely spaced (71.4%) and curved horns (76%). They also mainly had small (66.7%), erected (96.2%) humps located at the cervicothoracic position (77.8%). All (100%) of the studied cattle had a straight face and a back profile as well as a sloppy rump. Medium (44.4%) or long (45.6%) tails were equally common and medium dewlap width were observed on most (72.1%) of the cattle. On the other hand, 57.6% of the males had medium perpetual sheath while naval flap was not observed on 53.2% of their female counterparts. A uniform coat colour pattern was observed on most (78%) of the cattle while all of them (100%) had straight-edged ears (Figure 3).

Comparing sexes, laterally oriented straight horns were more frequently observed in males than females. The majority of females had an erect hump while some males had a dropping hump. Males also had larger humps located at the thoracic position while females possessed small humps located at the cervicothoracic position. Comparing breeds, a higher proportion of narrow horn spacing was observed in Jemjem cattle. However, no significant differences were observed among the cattle breeds in terms of most of the qualitative characteristics.

Morphometric traits

Means (least squares), standard errors and pairwise comparisons showing the effect of breed on the morphometric traits of the studied male and female cattle populations are presented in Table 4. Relative differences among breeds were observed more in females than males. Within females, Bale cows had the largest body length (101.6cm), heart girth (139.4cm) and hock circumference (28.8cm). The Arsi cows had the smallest body length (97.1cm), pelvic width (29.5cm) and muzzle circumference (36.1cm) while their horns were the longest (22.6cm). The Jemjem cows had relatively intermediate measurements for most of the traits including body length (99.7cm), pelvic width (30.5cm) and hock circumference (27.6cm). Similarly, the Bale males had the largest heart girth (150.5cm) and hock circumference (30.7cm).

Multivariate analysis

Stepwise discriminant analysis

All nine morphometric traits were used in discriminating the females while only six morphometric traits were used to discriminate the males. The three most important morphometric variables used in discriminating the cattle breeds were heart girth, muzzle circumference and horn length among females, and heart girth, horn length and pelvic width among males (Table 5). However, low partial R-Square and F-values were observed.

Figure 2. Distribution of coat colour among three cattle breeds and separated by sex.

Figure 3. A, Arsi cattle; B, Bale cattle; C, Jemjem cattle. Female individuals on the left, male individuals on the right.

Table 3. Percentage distributions of qualitative characteristics of cattle populations by sex and breed. χ^2, chi-square; P, chi-square probabilities; NS, not significant; NA, not available; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.0001$

Qualitative traits		Breed					Sex				Overall mean
		Arsi	Bale	Jemjem	χ^2 value	P	Male	Female	χ^2 value	P	
Number of animals		152	137	152			99	342			
Horn spacing	Narrow	13.2	24.1	48.0	47.2	***	29.3	28.4	0.03	NS	28.6
	Wide	86.8	75.9	52.0			70.7	71.6			71.4
Horn shape	Straight	17.1	32.1	23.7	8.9	*	47.5	17.3	38.4	***	24.0
	Curved	82.9	67.9	76.3			52.5	82.7			76.0
Horn orientation	Lateral	17.1	29.9	22.4	27.0	**	45.5	16.4	44.2	***	22.9
	Upright	19.1	5.1	5.9			14.1	9.0			10.2
	Forward	63.8	62.8	70.4			40.4	73.1			65.8
	Dropping	0	2.2	1.3			0	1.5			1.1
Colour pattern	Uniform	82.9	85.4	66.5	29.6	***	81.8	76.9	1.3	NS	78.0
	Spotty	1.3	0.7	7.2			2.0	3.5			3.2
	Pied	11.8	8.8	23.7			13.2	15.5			15.0
	Shaded	4.0	5.1	2.6			3.0	4.1			3.8
Coat colour	Black	63.2	61.3	58.5	37.9	***	61.6	60.8	4.5	NS	61.0
	Red	21.0	24.1	8.6			21.2	16.7			17.7
	Black + white	9.2	11.7	29.6			16.2	17.3			17.0
	Grey	2.6	2.2	2			1.0	2.6			2.3
	Red + white	4	0.7	1.3			0	2.6			2
Ear shape	Straight edged	100	100	100	NA	NS	100	100	NA	NS	100
Hump shape	Erect	94.7	96.3	97.4	1.4	NS	82.8	100	61.1	***	96.2
	Dropping	5.3	3.7	2.6			17.2	0			3.8
Hump size	Small	72.4	59.8	67.1	12.9	*	9.1	83.3	224.4	***	66.7
	Medium	19.7	29.2	30.3			59.6	16.7			26.3
	Large	7.9	11.0	2.6			31.3	0			7.0
Hump position	Thoracic	25.7	24.8	16.5	4.5	NS	80.8	5.3	253.5	***	22.2
	Cervico-thoracic	74.3	75.2	83.5			19.2	94.7			77.8
Face profile	Straight	100	100	100	NA	NS	100	100	NA	NS	100
Back profile	Straight	92.8	92.0	91.5	0.18	NS	91.9	92.1	0.004	NS	92.0
	Curved	7.2	8.0	8.5			8.1	7.9			8.0
Rump profile	Sloppy	100	100	100	NA	NS	100	100	NA	NS	100
Tail length	Short	13.2	5.1	11.2	9.6	*	9.1	10.2	0.85	NS	10.0
	Medium	45.4	40.2	47.4			48.5	43.3			44.4
	Long	41.4	54.7	41.4			42.4	46.5			45.6
Dewlap width	Small	5.9	2.9	5.2	16.0	**	0	6.1	82.3	***	4.8
	Medium	69.1	65.0	81.6			43.4	80.4			72.1
	Large	25.0	32.1	13.2			56.6	13.5			23.1
Naval flap width	Absent	58.9	53.8	48.2	7.3	NS	-	53.2	NA	NA	53.2
	Small	28.6	33.3	36.5			-	33.1			33.1
	Medium	11.6	7.5	12.4			-	10.8			10.8
	Large	0.9	5.4	2.9			-	2.9			2.9
Perpetual sheath	Small	25.0	29.6	26.7	4.8	NS	27.3	-	NA	NA	27.3
	Medium	52.5	56.8	73.3			57.6	-			57.6
	Large	22.5	13.6	0			15.1	-			15.1

Table 4. The effect of breed of the cattle on their morphometric measurements by sex. *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.0001$; NS, Not significant. Means within a row bearing different superscripts are significantly different; ^{a} is given to the highest value.

Traits	Females			
	Arsi	Bale	Jemjem	p
Number	112	93	137	
Body length	97.1±0.56^{c}	101.6±0.61^{a}	99.7±0.52^{b}	***
Heart girth	132.1±0.63^{b}	139.4±0.68^{a}	132.0±0.58^{b}	***
Height at withers	108.9±0.51^{ab}	109.4±0.55^{a}	107.4±0.47^{b}	*
Pelvic width	29.5±0.19^{b}	30.6±0.21^{a}	30.5±0.18^{a}	***
Muzzle circumference	36.1±0.19^{b}	37.4±0.20^{a}	37.8±0.17^{a}	***
Ear length	16.2±0.15	15.8±0.16	15.9±0.13	NS
Horn length	22.6±0.55^{a}	19.3±0.60^{b}	16.7±0.50^{c}	***
Cannon bone length	16.9±0.13^{ab}	16.5±0.15^{b}	17.1±0.12^{a}	**
Hock circumference	27.4±0.16^{b}	28.8±0.18^{a}	27.6±0.15^{b}	***
	Males			
	Arsi	Bale	Jemjem	p
Number	40	44	15	
Body length	105.2±1.03	108.1±1.04	105.1±1.70	NS
Heart girth	144.7±1.25^{b}	150.5±1.26^{a}	140.7±2.04^{b}	***
Height at withers	115.3±0.98^{a}	115.6±0.99^{a}	110.7±1.61^{b}	*
Pelvic width	30.0±0.37	30.3±0.37	29.7±0.60	NS
Muzzle circumference	39.2±0.33^{b}	40.3±0.34^{a}	39.6±0.55^{ab}	*
Ear length	16.4±0.22^{a}	15.8±0.22^{b}	15.8±0.36^{ab}	*
Horn length	23.8±1.25^{a}	24.4±1.26^{a}	15.3±2.05^{b}	**
Cannon bone length	17.5±0.24^{a}	16.7±0.24^{b}	17.4±0.39^{ab}	*
Hock circumference	29.6±0.30^{b}	30.7±0.31^{a}	28.8±0.50^{b}	**

Table 5. Order of traits used in discriminating the cattle populations from different breeds.

Sex	Step	Variables entered	Partial R-Square	F value	Pr > F	Wilks' Lambda	Pr < Lambda
Females	1	Heart girth	0.1832	38.01	< 0.0001	0.8168	< 0.0001
	2	Muzzle circumference	0.1394	27.31	< 0.0001	0.7029	< 0.0001
	3	Horn length	0.1928	40.25	< 0.0001	0.5674	< 0.0001
	4	Pelvic width	0.0752	13.66	< 0.0001	0.5247	< 0.0001
	5	Canon bone length	0.0583	10.37	< 0.0001	0.4941	< 0.0001
	6	Ear length	0.0307	5.29	0.0055	0.4789	< 0.0001
	7	Hock circumference	0.0278	4.76	0.0091	0.4656	< 0.0001
	8	Body length	0.0201	3.41	0.0341	0.4562	< 0.0001
	9	Height at withers	0.0189	3.19	0.0425	0.4476	< 0.0001
Males	1	Heart girth	0.2543	16.37	< 0.0001	0.7456	< 0.0001
	2	Horn length	0.1577	8.90	0.0003	0.6280	< 0.0001
	3	Pelvic width	0.0900	4.65	0.0119	0.5715	< 0.0001
	4	Canon bone length	0.0974	5.02	0.0085	0.5158	< 0.0001
	5	Height at withers	0.0568	2.77	0.0677	0.4865	< 0.0001
	6	Ear length	0.0422	2.01	0.1404	0.4659	< 0.0001

Discriminant analysis

Results of the discriminant analysis show moderate classification (65.83%) of individual animals into their corresponding breed with an error rate of 34.17% (Table 6). The highest classification into their respective breed was observed in Arsi cows while the lowest classification was observed in Arsi males. o

Canonical discriminant analysis

Multivariate statistics including eigenvalues using the first and the second canonical structures (Can 1 and Can 2) are shown in Table 7. In classifying the cattle breeds, Can 1 had a higher proportion for females (0.6066) and males (0.7876) than Can 2. However, the lowest eigenvalues were observed for both canonical structures under both sexes.

Pairwise Mahalanobis distances between the breeds studied are presented in Table 8. The shortest and the longest distances were observed among males. The shortest distance (1.77) was observed between Arsi and Bale males while Bale and Jemjem oxen were related distantly (7.31). The overall results showed the lowest and non-significant distances among Arsi, Bale and Jemjem cattle breeds.

A plot of Can 1 and Can 2 showing the maximum separation among the cattle breeds is presented in Figure 4. In line with the result of the Mahalanobis distances, females were separated less than males. Accordingly, Arsi, Bale and Jemjem cows were inseparable and categorized in the same group while relative separation was observed between Arsi and Jemjem cows. Similarly, a relative separation between Bale and Jemjem oxen was also observed.

Discussion

Qualitative characteristics

Due to their easily observable nature, unique qualitative characteristics can be used for breed differentiation. Alongside other morphometric and morphological traits, similarities in coat colour and coat colour pattern among breeds may indicated genetic similarity (Getachew *et al*, 2014; Mustefa *et al*, 2024). According to Getachew *et al* (2014), the majority (73.62%) of Ogaden cattle exhibited a uniform body colour pattern, with most (69.33%) having a grey coat colour. Similarly, Mustefa *et al* (2024) suggested that the Guraghe and Jimma cattle populations might belong to the same breed based on their phenotypic similarities. They reported that 66% of Guraghe and 77% of Jimma cattle populations had a uniform coat colour pattern with 55% of Guraghe and 65% of Jimma cattle populations having a red coat (Mustefa *et al*, 2024). In line with these results, the cattle breeds examined in the current study – Arsi, Bale and Jemjem – shared similarities in both coat colour and coat colour patterns. These phenotypic similarities suggest a potential genetic link between these breeds. However, contrasting reports from Mustefa *et al* (2023) on Harar cattle, which displayed a diverse range of coat colours and patterns, highlight the need for further molecular characterization to confirm the results of the phenotypic study.

The dominantly black coat colour and uniform body colour pattern observed in this study are in line with the results of Yimamu (2014) on Arsi cattle. The dominance of dark colours over light colours might be associated with the highland environment (Titto *et al*, 2016), since animals with darker coats are better adapted to cold conditions by absorbing more heat than lighter colour coats (Titto *et al*, 2016). Moreover, the dominantly observed black coat colour might also be associated with farmers' preferences and selection criteria as black was favoured in the studied areas.

Beyond coat colour, similarities in other qualitative characteristics were also observed. The resemblance in horn, hump, tail, dewlap, naval flap and perpetual sheath besides their perfect match in the face, back and rump profiles among Arsi, Bale and Jemjem challenge their classifications as different breeds. The slight differences noted can be taken as within-breed differences. Such differences in cattle sampled from different locations were reported by Terefe *et al* (2015) in Mursi cattle and Mustefa *et al* (2021) in Raya cattle.

Morphometric traits

Results of morphometric traits, alongside qualitative traits, can provide reliable information for quantifying the degree of relationships among breeds. In this study, the observed qualitative similarities among Arsi, Bale and Jemjem were also supported by quantitative measurements. Significant differences in morphometric measurements that would indicate distinct breeds were not observed. This was also in line with Mustefa *et al* (2024), who reported comparable morphometric measurements between Guraghe and Jimma cattle populations suggesting they belong to the same breed.

As noted in the qualitative analysis, the differences observed among the three cattle breeds might be due to within-breed variation (Mustefa *et al*, 2024). Bale cows seem to be the largest, with higher measurement values for body length, heart girth and hock circumference. Intermediate measurement values were observed in Jemjem cows, while Arsi cows were the smallest, with lower values for body length, pelvic width and muzzle circumference although they possessed the longest horns. However, Yimamu (2014) reported relatively higher measurements for body length, heart girth and height at withers for Arsi cattle in the same study area.

When compared to other Ethiopian breeds, the morphometric values of Arsi, Bale and Jemjem cattle were lower than Afar cattle (Tadesse *et al*, 2008), Begait cattle (Ftiwi, 2015), Begaria cattle (Getachew *et al*, 2020), Fogera cattle (Girma *et al*, 2016), Gojjam Highland cattle (Getachew and Ayalew, 2014), Harar cattle (Mustefa, 2023), Kereyu cattle (Nigatu and Tadesse, 2020), Nuer cattle (Minuye *et al*, 2018), Ogaden cattle (Mustefa *et al*, 2023) and Raya cattle (Mustefa *et al*, 2021). On the other

Table 6. Number and (percentage) of observations classified into breed based on discriminant analysis of morphometric traits. The diagonal bold values indicate the correct classifications of sampled animals into their respective breed.

Sex	From breed	Arsi	Bale	Jemjem	Total
Females	Arsi	**77 (68.75)**	20 (17.86)	15 (13.39)	112 (100)
	Bale	18 (19.35)	**60 (64.52)**	15 (16.13)	93 (100)
	Jemjem	24 (17.52)	25 (18.25)	**88 (64.23)**	137 (100)
	Error rate	0.3125	0.3548	0.3577	**0.3417**
Males	Arsi	**23 (57.50)**	9 (22.50)	8 (20.00)	40 (100)
	Bale	11 (25.00)	**30 (68.18)**	3 (6.82)	44 (100)
	Jemjem	2 (13.33)	3 (20.00)	**10 (66.67)**	15 (100)
	Error rate	0.4250	0.3182	0.3333	**0.3588**

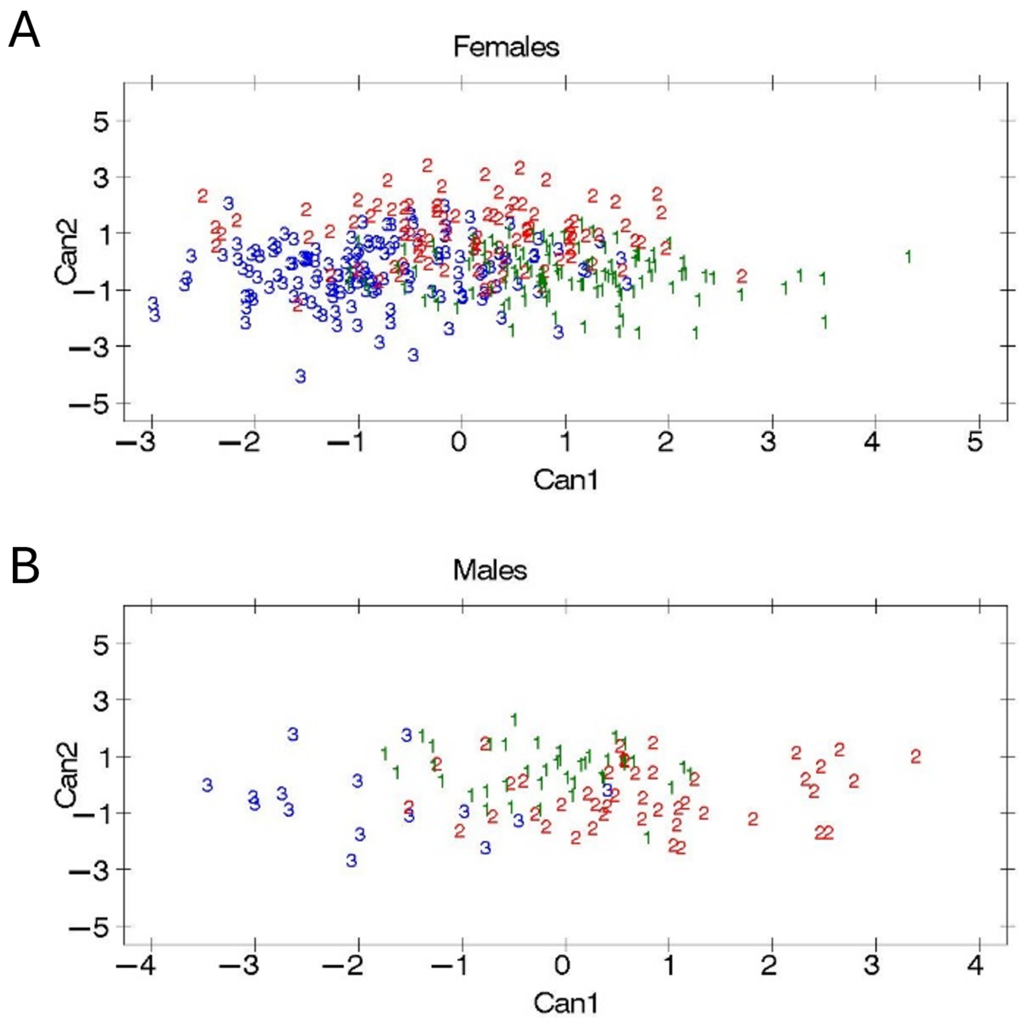

Figure 4. Plots of canonical discriminant analysis of Ethiopian cattle based on morphometric traits. A, females; B, males. Breed is indicated by numbers: 1, Arsi; 2, Bale; 3, Jemjem.

Table 7. Multivariate statistics outputs from the two canonical structures. Can, canonical structure.

	Females		Males	
Multivariate Statistics	**Can 1**	**Can 2**	**Can 1**	**Can 2**
Canonical correlation	0.6138	0.5307	0.6814	0.4353
Proportion	0.6066	0.3934	0.7876	0.2124
Eigenvalue	0.6047	0.3921	0.8670	0.2338

Table 8. Pairwise squared distances between breeds. Females above diagonal, males below diagonal.

From breed	Arsi	Bale	Jemjem
Arsi	**0**	2.88	3.32
Bale	1.77	**0**	2.72
Jemjem	4.21	7.31	**0**

hand, the morphometric values of Abergelle and Irob cattle (Zegeye *et al*, 2021) were lower than the Arsi, Bale and Jemjem. Comparable morphometric values were also reported in Arado cattle (Genzebu *et al*, 2012), Gofa cattle (Kebede *et al*, 2017), Horro cattle (Bekele, 2015) and Mursi cattle (Terefe *et al*, 2015).

Effect of sex

In most morphometric traits, males were observed to be larger than females. Such differences might be attributed to the secretion of testosterone in males, which promotes skeletal development and muscle mass growth (Baneh and Hafezian, 2009). The endocrine system plays a significant role in differentiating the two sexes, with the growth-limiting effects of estrogen being more prominent in females (Chriha and Ghadri, 2001; Baneh and Hafezian, 2009). The findings of this study are in line with the reports of Mustefa *et al* (2023) on Harar and Ogaden cattle, Mustefa *et al* (2021) on Raya cattle, and Terefe *et al* (2015) on Mursi cattle.

Multivariate analysis

Morphometric traits were identified and ranked based on their ability to differentiate between the cattle breeds. In line with the results of Mustefa *et al* (2024) on Guraghe cattle, lower partial R-Square and F-values (Table 5) were observed in the stepwise analysis, showing that morphometric traits have limited potential to discriminate the breeds into different categories. The higher the R-Square and F-values the higher the potential of the traits in differentiating the cattle breeds (Mustefa *et al*, 2023).

The higher error rate (Table 6) suggests greater shared similarities among the breeds, which reduces the chances of clearly categorizing the breeds into different clusters. On the other hand, the lower the error rate, the lower the similarities shared among the breeds. This highlights the uniqueness of each breed. The moderate classification with a considerably higher error rate (34.17%) observed in the current study, showed the presence of shared similarities among the breeds. An error rate of 1% was reported in classifying the phenotypically unrelated Harar and Ogaden cattle breeds (Mustefa *et al*, 2023).

The low eigenvalues reported for both canonical structures in both sexes (Table 7) do not support the classification of the animals into different breeds. An eigenvalue higher than 1 is accepted to approve the discrimination analysis. If the value is lower than 1, the discrimination of the studied animals into different breeds is not significant. In this study, the observed low eigenvalue disproved the presence of three breeds in the study area.

Similarly, the higher the Mahalanobis distances between breeds (Table 8) the higher the possibility of classification into different clusters. However, the Mahalanobis distances in the current study were low although Jemjem males showed relatively higher distances. This could be due to the small sample size of Jemjem oxen. The accuracy of the analysis increases with larger sample sizes. Due to the low eigenvalue (< 1) in the multivariate analysis, the distances observed were not significant, supporting the conclusion that the studied cattle breeds are phenotypically inseparable.

Conclusion

According to the univariate (morphometric measurements and qualitative characteristics) as well as multivariate analysis results, the Arsi, Bale and Jemjem cattle breeds were found to be phenotypically inseparable. However, the observed phenotypic similarities among these breeds do not necessarily mean that they are genetically the same. Therefore, further molecular characterization is recommended to quantify the degree of genetic relationships among these breeds.

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Author contributions

All authors contributed to the study's conception and design. Material preparation and data collection were performed by Amine Mustefa, Awoke Melak, Hizkel Kenfo, Seble Sinke and Ahmed Abdela. Data analysis and writing the first manuscript draft were performed by Amine Mustefa. Abebe Hailu reviewed the manuscript. All authors commented on the various versions of the manuscript, and read and approved the final manuscript.

Data availability statement

The datasets generated and/or analyzed during the current study are not publicly available due to data confidentiality but are available from the corresponding author upon reasonable request.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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