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# Phenotypic diversity between and within Harar and Ogaden cattle breeds in eastern Ethiopia: The first step for conservation

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**Abstract:** Fourteen morphological and eight morphometric traits on a total of 456 adult cattle (354 cows and 102 oxen) from 5 purposively selected districts were recorded to characterize the cattle populations in eastern Ethiopia. Frequency, general linear model and multivariate analysis procedures of Statistical Analysis Software (SAS 9.0) were used to analyze the data. The morphological similarities among the cattle populations from Tulo, Jarso and Fedis districts confirmed their uniqueness and belonging to Harar cattle. Morphological similarities were also observed between the cattle populations from Jigjiga and Kebri Beyah districts, which categorize them as Ogaden cattle. The Harar cattle were characterized by their forward-oriented, widely spaced, and medium-length horns while the Ogaden cattle possessed upright-oriented, narrowly spaced, short horns. The majority of the Ogaden cattle had grey body colour while the Harar cattle had multiple body colours with red combined with white and black observed frequently. Most of the morphometric measurement values were higher for the oxen, while the cows had longer horns. Moreover, Ogaden cattle had higher morphometric parameters than Harar cattle. According to the multivariate analysis results, the cattle populations in the study area were separated into two breeds – Harar and Ogaden. However, these results only showed phenotypic differences, which might not necessarily be due to genetic differences. Therefore, further molecular characterization is recommended to understand their level of relationships which will help to design appropriate conservation and breeding programmes.

**Keywords:** Breeds, Characterization, Indigenous, Morphology, Morphometric, Multivariate

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## Introduction

The cattle population size of Ethiopia, 70.3 million head (Central Statistical Agency, 2021), is the largest in Africa and more than double the cattle population registered by Chad (32.2 million) which is the second country with high cattle population (Statista, 2020). Cattle genetic resources, the major contributor to the livestock sector, serve as sources of milk, meat, draught power, hide, manure, nutrient recycling and foreign exchanges for Ethiopia (Central Statistical Agency, 2021). Due to the very important role cattle genetic resources play in the economy of the country, various diversity and genetic improvement studies have been made so far to ensure their sustainable utilization. Diversity studies in animal genetic resources are important to better understand the breed and design appropriate breeding programmes for current and future research and development works (FAO, 2012). Variation within and among breeds is among the key inputs in genetic improvement and conservation programmes; the more diverse the population the more likely it leads to bring genetic improvement (Falconer, 1989).

Identification, phenotypic and genetic characterization, and advanced performance evaluation can help

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us understand the diversity of a given population. The first diversity assessment of Ethiopian cattle genetic resources was made by the International Livestock Centre for Africa (ILCA), now the International Livestock Research Institute (ILRI), in 1992 (Rege, 1999; Rege and Tawa, 1999). It sought to determine the status and compile information on the characteristics of cattle. It does not constitute the level of assessment required to make decisions on use and conservation, as the information was incomplete due to its very broad brush survey. However, it provides a basis for additional, targeted surveys (Rege, 1999; Rege and Tawa, 1999; Mustefa *et al*, 2021).

According to Ethiopia's focal point for genetic resources, the Ethiopian Biodiversity Institute, Ethiopia possesses 28 indigenous cattle breeds; Abergelle, Anuak, Adwa, Afar, Ambo, Arado, Arsi, Bale, Begait, Begaria, Borena, Fogera, Gofa, Gojam Highland Zebu, Guraghe, Hammer, Harar, Horro, Irob, Jem-Jem, Jijiga, Kereyu, Medenes, Mursi, Ogaden, Raya, Sheko, and Smada (Rege and Tawa, 1999; EBI, 2016). Among the listed cattle breeds, some (Adwa, Ambo, Bale, Guraghe, Hammer, Harar, Jem-Jem, Jijiga, and Smada) do not have a detailed description of their physical appearance. Therefore, it is important to consider filling the missing information to capture a country-wide picture.

According to Getachew *et al* (2014), Ogaden cattle are thought to be a variety of the Borena cattle found in the Ogaden area of the Somali region of Ethiopia and bordering East Hararghe. They have a well-developed hump, large dewlap and short horns. They are mainly kept for milk production but are good beef animals. The Ogaden cattle were also reported to be distributed up to Jigjiga and parts of East Hararghe (Rege and Tawa, 1999; Mengesha, 2019). On the other hand, according to the reports of Rege and Tawa (1999), the Harar cattle are found in the East and West Hararghe plateau. They have short, thick horns and well-developed dewlaps. The common coat colours are black, roan and red and are used primarily for draught. These two cattle breeds are found adjacent to one another. To quantify the level of relationship between them as well as to know the available cattle diversity in that area, phenotypic characterization is required. Moreover, phenotypic characterization is a crucial first step for *in situ* conservation. The current study aims to phenotypically characterize these two cattle breeds and to quantify the level of relationship between them.

## Materials and methods

### Study areas

This study was conducted in five districts of three zones in two regions: Tulo district of West Hararghe zone, Jarso and Fedis districts of East Hararghe zone of Oromia region and Jigjiga and Kebri Beyah districts of Fafen zone of Somali region (Figure 1). The weather conditions, altitude, ethnicity, and human and cattle population sizes of the sampled districts are presented in Table 1.

### Site selection

According to Rege and Tawa (1999), Harar cattle were found in East and West Hararghe zones of the Oromia region. Similarly, Getachew *et al* (2014) reported the distribution of Ogaden cattle to be the Somali region and adjacent areas of eastern Oromia. Therefore, the current study took representative samples from the two breeds of cattle. Accordingly, for the Harar cattle, Tulo district was randomly selected from West Hararghe zone while Jarso and Fedis districts were randomly selected from East Hararghe zone. On the other hand, Jigjiga and Kebri Beyah districts were selected randomly from Fafen zone to represent Ogaden cattle. The kebeles (sampling sites) within each district were categorized into highland and lowland areas. One kebele from the highland and one kebele from the lowland areas were selected randomly. Households were also randomly selected from each kebeles (sampling sites) and 2–3 adult animals (four years old and above) were sampled randomly from each household.

### Data collection

Data collection procedures were adapted from the FAO guidelines for the *Phenotypic Characterization of Animal Genetic Resources* (FAO, 2012). Sampled cattle were carefully handled by trained labourers and their owners. To avoid measurement error, the cattle were made to stand properly on flat grounds with parallel legs. Four researchers were involved in the data collection: two for the quantitative and two for the qualitative data recording. Measurements were carried out by the same researcher throughout the study to minimize subjectivity errors. Data recording was carried out early in the morning before the animals were fed and watered. Textile measurement tape in a centimetre unit was used to record quantitative data. Eight morphometric/quantitative (Table 2) and fourteen morphological/qualitative traits (Table 3, Figure 2) were recorded on a total of 456 adult cattle (354 females and 102 males).

### Data analysis

#### Univariate analysis

Data entry and management were performed using Microsoft Excel© worksheet (Microsoft Office 2016). UNIVARIATE procedure of Statistical Analysis Software (SAS) 9.0 (SAS Institute, 2002) was used to test the normality of the morphometric data. Data on morphological/qualitative traits were subjected to chi-square ($\chi^2$) tests of the frequency (FREQ) procedure of SAS 9.0 software (SAS Institute, 2002) . Qualitative data analysis was performed using the following model by fitting sex, breed and location as class variables. $Y_{ijk} = \mu + S_i + B_j + L_k + e_{ijk}$ where $Y_{ijk}$ is an observation, $\mu$ is the overall mean, $S_i$ is the fixed effect of $i^{th}$ sex, $B_j$ is

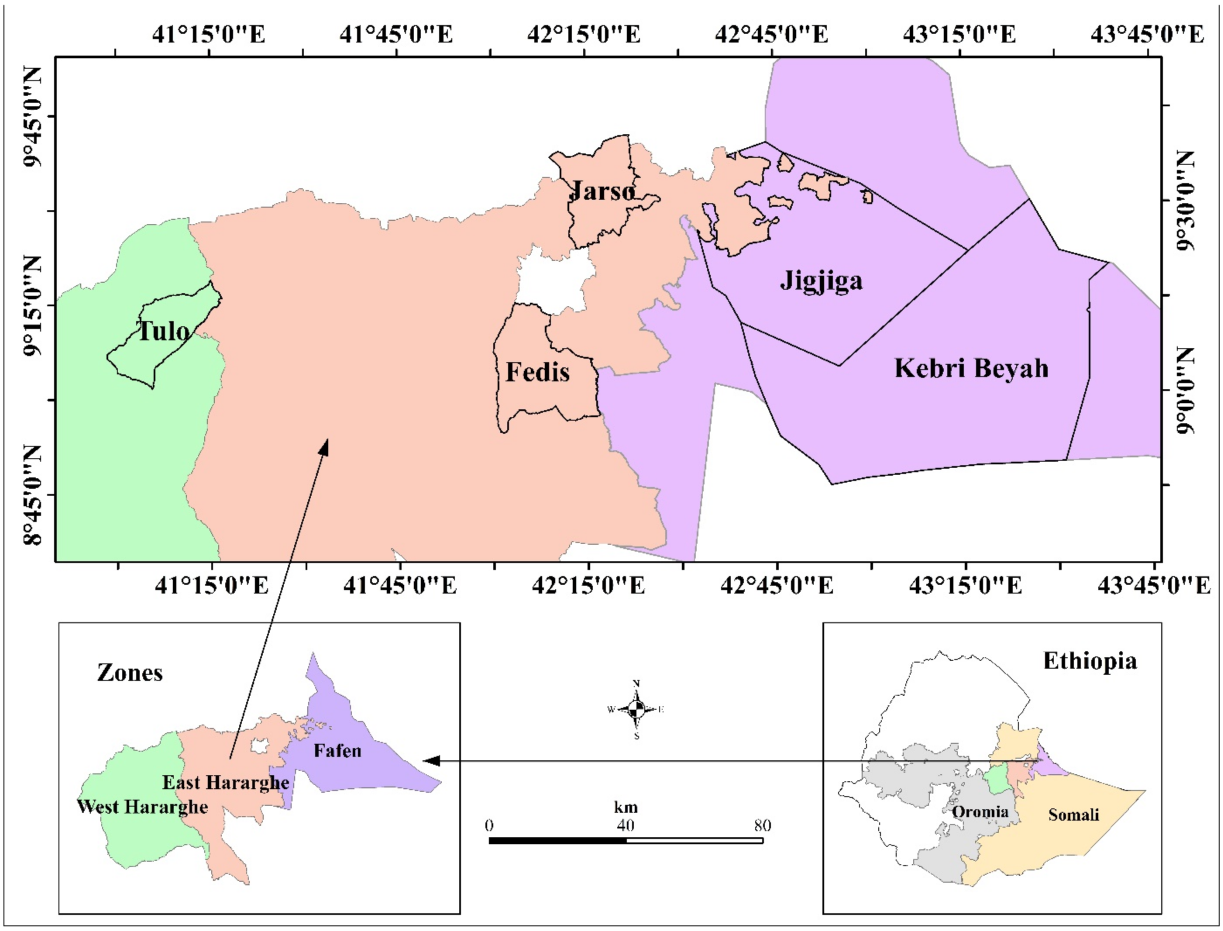


**Figure 1.** Map of the study areas

the fixed effect of $j^{th}$ breed, $L_k$ is the fixed effect of $k^{th}$ location, and $e_{ijk}$ is the random error attributed to the $n^{th}$ observation.

On the other hand, morphometric data analysis was performed separately for males and females by fitting location and breed as fixed variables. Morphometric data were analyzed using the general linear model (GLM) procedure of SAS 9.0 software, with adjusted Tukey-Kramer test to separate the least square means (LSM). Morphometric data analysis was performed using the following model: $Y_i = \mu + L_i + e_i$ where $Y_i$ is an observation, $\mu$ is the overall mean, $L_i$ is the fixed effect of $i^{th}$ location, and $e_i$ is the random error attributed to the $n^{th}$ observation. $Y_{ij} = \mu + B_i + L_j + e_{ij}$ where $Y_{ij}$ is an observation, $\mu$ is the overall mean, $B_i$ is the fixed effect of $i^{th}$ breed, $L_j$ is the fixed effect of $j^{th}$ location, and $e_{ij}$ is the random error attributed to the $n^{th}$ observation.

## Multivariate analysis

Quantitative measurements that better discriminate the cattle populations from different locations were identified using the forward selection method of the stepwise discriminant function analysis (STEPDISC) procedure of SAS 9.0. The discriminant function analysis (DISCRIM) procedure of SAS 9.0. was also used to assign observations to locations and evaluate probabilities of misclassifications. A linear combination

**Table 1.** Weather and population-related information of the selected districts (City Population, 2007; Keskes *et al*, 2013; EHZLFDO, 2018; WHZLFDO, 2018; Ayana, 2019; UNHCR, 2020; Kebede and Utta, 2021; Abdi and Shiferaw, 2022)

| Agroecology | Tulo | Jarso | Fedis | Jigjiga | Kebri Beyah |
|---|---|---|---|---|---|
| Human population projection 2022 | 215,337 | 165,712 | 161,214 | 417,688 | 242,880 |
| Area (km$^2$) | 430.6 | 515.1 | 720.8 | 2,859 | 4,839 |
| Temperature (°C) | 17–32 | 12–25 | 14–28 | 16–29 | 16–27 |
| Rainfall (mm) | 600–900 | 400–900 | 516.3 | 300–500 | 582.4 |
| Altitude (m.a.s.l.) | 1,600–2,400 | 1,500–3,060 | 1,702 | 500–1,600 | 1,530 |
| Cattle population | 131,643 | 76,873 | - | - | - |
| Ethnicity | Oromo | Oromo | Oromo | Somali | Somali |

**Table 2.** Description of the collected morphometric traits. Adapted from FAO (2012). Measurement was performed using a centimetre (cm) unit.

| No. | Morphometric traits | Definitions |
|---|---|---|
| 1 | Body length | Horizontal length from the point of the shoulder to the pin bone |
| 2 | Heart girth | Measurement around the animal right behind its front legs |
| 3 | Height at withers | Height from the bottom of the front foot to the highest point of the withers |
| 4 | Pelvic width | Horizontal distance between the extreme lateral points of the hook bone (tuber coxae) of the pelvis |
| 5 | Muzzle circumference | Circumference of the mouth a little above the nostrils and around the point where the dewlap meets the chin |
| 6 | Ear length | Length of the back side of the ear from the root to the tip |
| 7 | Horn length | The longest distance from the root of the horn to its tip along the outer curvature |
| 8 | Cannon bone length | Distance from the lateral tuberculum of the os metacarpale IV to the fetlock joint |

of morphometric measurements that provide maximal separations between locations was performed using the canonical discriminant function analysis (CANDISC) procedure of SAS 9.0. The scored canonical variables were used to plot pairs of canonical variables to get a visual interpretation of location differences. Pairwise squared Mahalanobis distances between locations were computed as: $D^2\,(i|j) = (x_i - x_j)^{'} cov^{-1} \quad (x_i - x_j)$. Where $D^2\,(i|j)$ is the distances between locations $i$ 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 $j^{th}$ populations.

# Results

## Morphological traits

The qualitative characteristics of both sexes (male and female) and both breeds (Harar and Ogaden) along with their chi-square values and levels of significance are presented in Table 3. Accordingly, sex and breed significantly ($p < 0.05$) affected the qualitative characteristics of the cattle populations. The majority of the males had straight-shaped lateral and upright horn orientation, shaded body colour pattern, large hump size located at thoracic position, and large dewlap width. On the other hand, the majority of the females had curved and forward-oriented horn, uniform body colour pattern, small hump size located at cervico-thoracic position, and medium dewlap width.

Moreover, the studied cattle breeds showed significantly different qualitative characteristics. The majority of Harar cattle had wide, curved and forward-oriented horn. They also possessed a sloppy rump with a small to medium hump located at the cervivo-thoracic position (Figure 3A). On the other hand, the Ogaden cattle possessed both narrow and wide horn spacing, straight and curved horn shapes, as well as flat and sloppy back profiles at an equivalent ratio. They also possessed an upright-oriented horn and a small hump placed at thoracic position. The majority of the Ogaden cattle also had a long tail with no naval flap (Figure 3B).

The qualitative characteristics of the cattle populations from the different locations along with their chi-square values and levels of significance are presented in Table 4. All the studied qualitative characteristics of the cattle populations were significantly ($p < 0.05$) affected by location differences. Accordingly, almost all the cattle populations from Tulo and Jarso districts possessed wide horn spacing, while this was comparably narrow in cattle from Jigjiga and Kebri Beyah districts. The horn shape of the majority of the cattle populations was curved while it was straight in cattle from Kebri Beyah district. Upright horn orientation was dominantly observed in cattle from Jigjiga and Kebri Beyah districts while it was oriented forward in cattle from Tulo and Jarso districts. The hump of the cattle populations from Jigjiga and Kebri Beyah districts was located at the thoracic position while the hump of most of the cattle populations from the other locations was located at the cervico-thoracic position. Flat-rump profile was observed in the majority of the cattle populations from Kebri Beyah district while all the cattle from Tulo, Jarso and Fedis districts had a sloppy rump. The majority of the cattle populations possessed a uniform body colour pattern, erected small hump, and straight back profile.

The body colour of the cattle populations disaggregated into male and female is presented in Figure 2A. Higher proportion of grey, red, white, and red + white body colours were observed in females than the males. On the other hand, black body colour and its mix with other colours (i.e. white + black and red + black) were observed frequently in the males.

Body colour disaggregated by cattle breeds (Harar and Ogaden) is presented in Figure 2B and representative examples shown in Figure 3. Grey body colour was observed predominantly in Ogaden cattle while several body colours were observed frequently in Harar cattle.

The body colour of the cattle populations from different locations is presented in Figure 2C. Location affected the body colour of the cattle populations significantly ($p < 0.0001$). Grey body colour was dominantly observed in Jigjiga and Kebri Beyah districts while cattle in Tulo and Jarso districts were predominantly red and the cattle population from Fedis district had white body colour followed by grey.

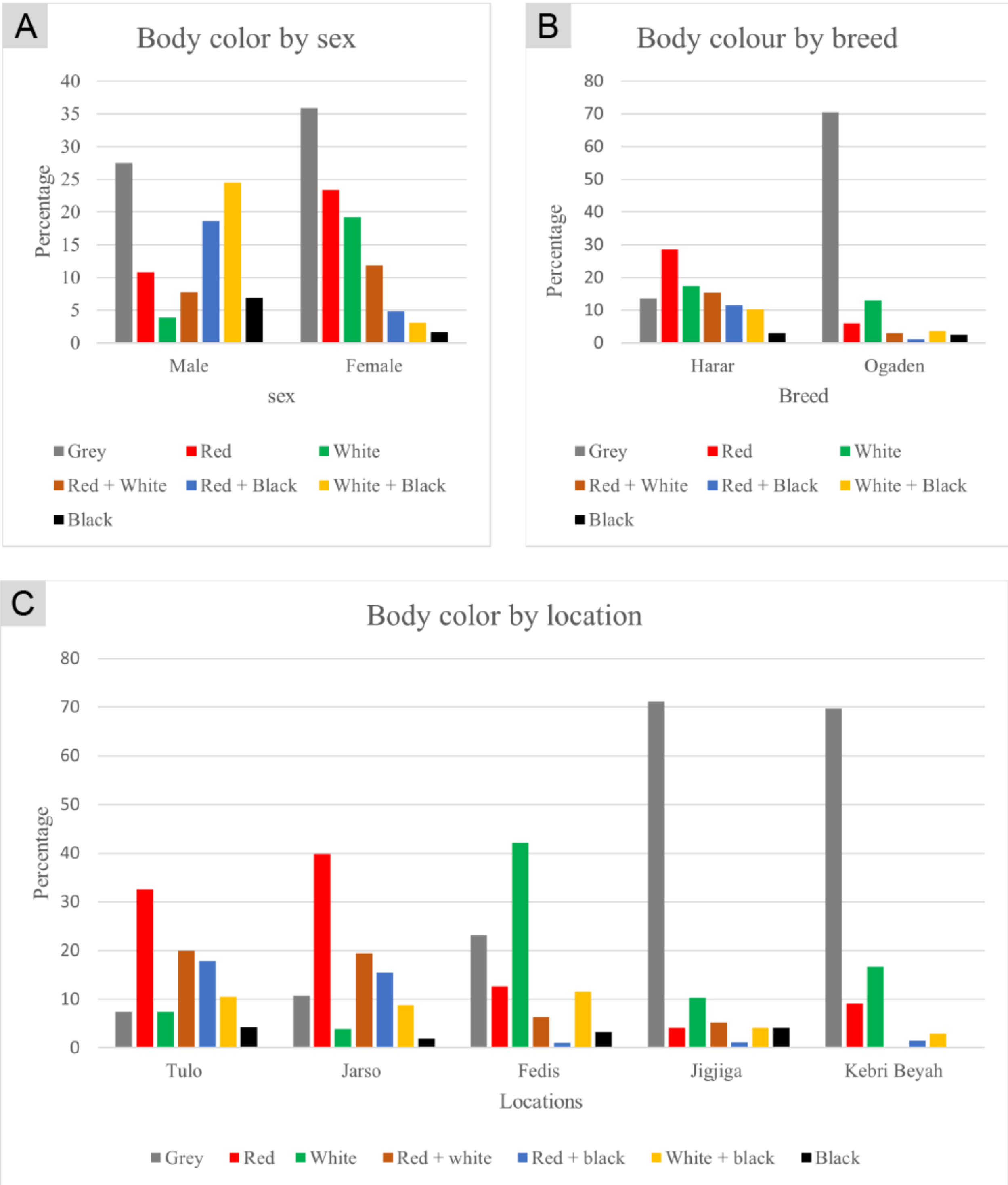


**Figure 2.** A: Effect of sex on body colour (chi-square value 93.2, $p < 0.0001$); B: Effect of breed on body colour (chi-square value 161.5, $p < 0.0001$); C: Effect of location on body colour (chi-square value 275.8, $p < 0.0001$).

**Table 3.** Percentages of qualitative characteristics of cattle populations by sex and breed. N, number of animals sampled; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.0001$; NS: not significant.

| Qualitative traits | | Sex | | | | Breed | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Male | Female | $X^2$ value | P | Harar | Ogaden | $X^2$ value | P |
| N | | 102 | 354 | | | 293 | 163 | | |
| Horn spacing | Narrow | 38.2 | 22.0 | 10.9 | ** | 11.6 | 50.9 | 84.9 | *** |
| | Wide | 61.8 | 78.0 | | | 88.4 | 49.1 | | |
| Horn shape | Straight | 65.3 | 24.0 | 61.9 | *** | 26.6 | 45.4 | 16.6 | *** |
| | Curved | 34.3 | 76.0 | | | 73.4 | 54.6 | | |
| Horn orientation | Lateral | 42.1 | 12.2 | 56.5 | *** | 25.2 | 7.4 | 126.3 | *** |
| | Upright | 36.3 | 33.6 | | | 15.7 | 67.5 | | |
| | Forward | 19.6 | 44.9 | | | 50.2 | 19.6 | | |
| | Dropping | 2.0 | 9.3 | | | 8.9 | 5.5 | | |
| Colour pattern | Uniform | 26.5 | 71.7 | 78.3 | ** | 55.0 | 73.6 | 20.3 | ** |
| | Spotty | 2.0 | 3.7 | | | 5.1 | 0 | | |
| | Pied | 9.8 | 4.8 | | | 6.1 | 5.5 | | |
| | Shaded | 61.7 | 19.8 | | | 33.8 | 20.9 | | |
| Hump shape | Erect | 86.3 | 100 | 50.1 | *** | 95.2 | 100 | 8.0 | ** |
| | Dropping | 13.7 | 0.0 | | | 4.8 | 0.0 | | |
| Hump size | Small | 12.7 | 78.0 | 232.7 | *** | 55.6 | 77.3 | 50.7 | *** |
| | Medium | 35.3 | 21.5 | | | 35.2 | 5.5 | | |
| | Large | 52.0 | 0.5 | | | 9.2 | 17.2 | | |
| Hump position | Thoracic | 85.3 | 44.1 | 54.1 | *** | 30.0 | 95.1 | 178.1 | *** |
| | Cervico-thoracic | 14.7 | 55.9 | | | 70.0 | 4.9 | | |
| Back profile | Straight | 96.1 | 88.1 | 5.5 | * | 89.1 | 91.4 | 0.6 | NS |
| | Curved | 3.9 | 11.9 | | | 10.9 | 8.6 | | |
| Rump profile | Flat | 29.4 | 12.7 | 16.1 | *** | 0.0 | 46.0 | 161.4 | *** |
| | Sloppy | 70.6 | 87.3 | | | 100 | 54.0 | | |
| Tail length | Short | 6.9 | 7.9 | 5.3 | NS | 10.2 | 3.1 | 31.4 | *** |
| | Medium | 24.5 | 35.9 | | | 40.3 | 20.9 | | |
| | Long | 68.6 | 56.2 | | | 49.5 | 76.0 | | |
| Naval flap width | Absent | - | 41.0 | NA | NA | 30.0 | 61.3 | 44.4 | *** |
| | Small | - | 42.4 | | | 45.7 | 36.3 | | |
| | Medium | - | 12.4 | | | 17.8 | 2.4 | | |
| | Large | - | 4.2 | | | 6.5 | 0.0 | | |
| Perpetual sheath | Absent | 7.8 | - | NA | NA | 0.0 | 20.5 | 50.1 | *** |
| | Small | 27.5 | - | | | 11.1 | 53.9 | | |
| | Medium | 62.7 | - | | | 88.9 | 20.5 | | |
| | Large | 2.0 | - | | | 0.0 | 5.1 | | |
| Dewlap width | Small | 2.0 | 22.9 | 65.7 | *** | 2.4 | 46.6 | 143.6 | *** |
| | Medium | 43.1 | 59.6 | | | 63.1 | 43.0 | | |
| | Large | 54.9 | 17.5 | | | 34.5 | 104 | | |

## Morphometric measurements

Least square means with their respective standard errors (LSM ± SE) and pairwise comparison of the morphometric measurements of both cattle breeds disaggregated by sex are presented in Table 5. Overall, males of each breed and location had higher size-related linear body measurements than their female counterparts. Both the Ogaden male and female cattle had higher measurements for most of the morphometric parameters (i.e. heart girth, height at withers, pelvic width, muzzle circumference, and canon bone length).

Some traits (horn, ear and body length) of the two breeds were sex dependent. Within the females, Harar cows had longer horns while in Ogaden cattle, males possessed longer horns. Similarly, Harar cows' body length was significantly higher than their counterparts from Ogaden while males' body length did not differ significantly. Moreover, Ogaden oxen's ear length was significantly higher than their counterparts from Harar while the value was not significantly different between the cows.

**Table 4.** Percentages of qualitative characteristics of cattle populations from different locations. N, number of animals sampled; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.0001$; NS, not significant.

| Qualitative traits | | Tulo | Jarso | Fedis | Jigjiga | Kebri Beyah | $X^2$ value | P |
|---|---|---|---|---|---|---|---|---|
| N | | 95 | 103 | 95 | 97 | 66 | | |
| Horn spacing | Narrow | 2.1 | 5.8 | 27.4 | 46.4 | 57.6 | 106.1 | *** |
| | Wide | 97.9 | 94.2 | 72.6 | 53.6 | 42.4 | | |
| Horn shape | Straight | 21.0 | 20.0 | 39.0 | 38.1 | 56.1 | 31.9 | *** |
| | Curved | 79.0 | 80.0 | 61.0 | 61.9 | 43.9 | | |
| Horn orientation | Lateral | 25.3 | 20.4 | 30.5 | 10.3 | 3.0 | 152.5 | *** |
| | Upright | 10.5 | 13.6 | 23.2 | 62.9 | 74.2 | | |
| | Forward | 61.0 | 56.3 | 32.6 | 20.6 | 18.2 | | |
| | Dropping | 3.2 | 9.7 | 13.7 | 6.2 | 4.6 | | |
| Colour pattern | Uniform | 50.5 | 46.6 | 68.4 | 74.2 | 72.7 | 33.8 | ** |
| | Spotty | 5.3 | 5.8 | 4.2 | 0 | 0 | | |
| | Pied | 8.4 | 6.8 | 3.2 | 7.2 | 3.0 | | |
| | Shaded | 35.8 | 40.8 | 24.2 | 15.6 | 24.3 | | |
| Hump shape | Erect | 89.5 | 97.1 | 99.0 | 100 | 100 | 24.2 | *** |
| | Dropping | 10.5 | 2.9 | 1.0 | 0 | 0 | | |
| Hump size | Small | 56.9 | 66.0 | 43.1 | 82.5 | 69.7 | 74.5 | *** |
| | Medium | 34.7 | 22.3 | 49.5 | 4.1 | 7.6 | | |
| | Large | 8.4 | 11.7 | 7.4 | 13.4 | 22.7 | | |
| Hump position | Thoracic | 27.4 | 26.2 | 36.8 | 91.8 | 100 | 181.8 | *** |
| | Cervico-thoracic | 72.6 | 73.8 | 63.2 | 8.2 | 0 | | |
| Back profile | Straight | 93.7 | 97.1 | 75.8 | 86.6 | 98.5 | 34.7 | *** |
| | Curved | 6.3 | 2.9 | 24.2 | 13.4 | 1.5 | | |
| Rump profile | Flat | 0 | 0 | 0 | 38.1 | 57.6 | 172.1 | *** |
| | Sloppy | 100 | 100 | 100 | 61.9 | 42.4 | | |
| Tail length | Short | 12.6 | 4.9 | 13.7 | 3.1 | 3.0 | 40.4 | *** |
| | Medium | 45.3 | 39.8 | 35.8 | 19.6 | 22.7 | | |
| | Long | 42.1 | 55.3 | 50.5 | 77.3 | 74.3 | | |
| Naval flap width | Absent | 23.4 | 32.4 | 34.2 | 70.5 | 45.6 | 62.3 | *** |
| | Small | 57.1 | 43.3 | 36.7 | 28.2 | 50.0 | | |
| | Medium | 16.9 | 16.2 | 20.2 | 1.3 | 4.4 | | |
| | Large | 2.6 | 8.1 | 8.9 | 0 | 0 | | |
| Perpetual sheath | Absent | 0 | 0 | 0 | 31.6 | 10.0 | 70.0 | *** |
| | Small | 33.3 | 3.5 | 0 | 42.1 | 65.0 | | |
| | Medium | 66.7 | 96.5 | 100 | 15.8 | 25.0 | | |
| | Large | 0 | 0 | 0 | 10.5 | 0 | | |
| Dewlap width | Small | 2.1 | 2.9 | 2.1 | 57.7 | 30.3 | 207.8 | *** |
| | Medium | 76.8 | 70.9 | 41.1 | 29.9 | 62.1 | | |
| | Large | 21.1 | 26.2 | 56.8 | 12.4 | 7.6 | | |

Least square means with their respective standard errors (LSM ± SE) and pairwise comparison of the morphometric measurements disaggregated by the five locations for both sexes are presented in Table 6. Most of the morphometric measurements were significantly affected by the location of the cattle populations. Significantly higher heart girth, pelvic width, muzzle circumference and cannon bone length values were observed for the populations from Jigjiga and Kebri Beyah districts while the horn length of Tulo and Jarso cows was significantly higher than the others. The shortest horn was registered in oxen from Fedis district.

## Multivariate analysis for discrimination of cattle populations

Cannon bone length, horn length and pelvic width were the three most important morphometric variables used in discriminating the cattle populations from different locations (Table 7). These results were confirmed by Wilk's lambda test where the selected variables made a highly significant ($p < 0.0001$) contribution in discriminating the cattle populations (Table 7).

Results of a location-wise discriminant function analysis (Table 8) show the overall classification of individual animals into their location (population). The

**Table 5.** Least square means (LSM ± SE) and pairwise comparisons of the morphometric measurements of both cattle breeds under both sexes. 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. *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.0001$; NS, not significant.

| Traits | Females | | | Males | | |
|---|---|---|---|---|---|---|
| | Harar | Ogaden | P | Harar | Ogaden | P |
| N | 230 | 124 | | 63 | 39 | |
| BL | 106.1 ± 0.38 | 104.2 ± 0.52 | ** | 108.6 ± 0.91 | 110.6 ± 1.16 | NS |
| HG | 140.0 ± 0.53 | 149.1 ± 0.72 | *** | 143.8 ± 1.17 | 165.6 ± 1.49 | *** |
| HW | 112.3 ± 0.30 | 113.6 ± 0.40 | * | 115.2 ± 0.73 | 120.9 ± 0.93 | *** |
| PW | 35.3 ± 0.16 | 38.5 ± 0.22 | *** | 33.5 ± 0.38 | 40.6 ± 0.48 | *** |
| MC | 38.6 ± 0.13 | 40.0 ± 0.17 | *** | 40.1 ± 0.30 | 44.6 ± 0.38 | *** |
| EL | 17.9 ± 0.11 | 17.8 ± 0.16 | NS | 18.0 ± 0.19 | 17.4 ± 0.24 | * |
| HL | 20.8 ± 0.54 | 17.2 ± 0.73 | *** | 13.1 ± 0.72 | 15.9 ± 0.92 | * |
| CBL | 20.6 ± 0.12 | 27.7 ± 0.16 | *** | 21.0 ± 0.22 | 27.6 ± 0.28 | *** |

**Table 6.** Least square means (LSM ± SE) in centimetre units and pairwise comparisons of the morphometric measurements of the cattle populations from different locations by sex. 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. *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.0001$; NS, not significant.

| Traits | Location | | | | | P |
|---|---|---|---|---|---|---|
| | Tulo | Jarso | Fedis | Jigjiga | Kebri Beyah | |
| **Females** | | | | | | |
| N | 77 | 74 | 79 | 78 | 46 | |
| BL | $106.7 \pm 0.66^{a}$ | $106.1 \pm 0.67^{ab}$ | $105.5 \pm 0.65^{ab}$ | $104.0 \pm 0.65^{b}$ | $104.5 \pm 0.85^{ab}$ | * |
| HG | $142.8 \pm 0.90^{b}$ | $139.0 \pm 0.92^{c}$ | $138.3 \pm 0.89^{c}$ | $147.9 \pm 0.89^{a}$ | $151.2 \pm 1.16^{a}$ | *** |
| HW | $112.9 \pm 0.51^{ab}$ | $112.4 \pm 0.52^{ab}$ | $111.6 \pm 0.50^{b}$ | $113.4 \pm 0.51^{ab}$ | $113.9 \pm 0.66^{a}$ | * |
| PW | $35.5 \pm 0.27^{c}$ | $35.6 \pm 0.28^{c}$ | $34.7 \pm 0.27^{c}$ | $37.7 \pm 0.69^{b}$ | $39.7 \pm 0.35^{a}$ | *** |
| MC | $38.9 \pm 0.22^{b}$ | $38.49 \pm 0.22^{b}$ | $38.3 \pm 0.22^{b}$ | $39.9 \pm 0.22^{a}$ | $40.1 \pm 0.28^{a}$ | *** |
| EL | $18.3 \pm 0.19^{a}$ | $17.5 \pm 0.20^{bc}$ | $18.0 \pm 0.19^{ab}$ | $18.1 \pm 0.19^{ab}$ | $17.1 \pm 0.25^{c}$ | ** |
| HL | $25.0 \pm 0.86^{a}$ | $21.9 \pm 0.88^{a}$ | $15.8 \pm 0.85^{b}$ | $17.8 \pm 0.86^{b}$ | $16.0 \pm 1.12^{b}$ | *** |
| CBL | $21.1 \pm 0.20^{c}$ | $20.7 \pm 0.20^{cd}$ | $20.1 \pm 0.20^{d}$ | $28.1 \pm 0.20^{a}$ | $27.0 \pm 0.26^{b}$ | *** |
| **Males** | | | | | | |
| N | 18 | 29 | 16 | 19 | 20 | |
| BL | 107.9 ± 1.69 | 110.4 ± 1.33 | 106.1 ± 1.79 | 109.16 ± 1.64 | 111.95 | NS |
| HG | $146.9 \pm 2.10^{b}$ | $145.2 \pm 1.66^{bc}$ | $138.0 \pm 2.23^{c}$ | $163.6 \pm 2.05^{a}$ | $167.5 \pm 1.99^{a}$ | *** |
| HW | $115.2 \pm 1.34^{b}$ | $116.9 \pm 1.05^{ab}$ | $112.3 \pm 1.42^{b}$ | $120.5 \pm 1.3^{a}$ | $121.3 \pm 1.27^{a}$ | *** |
| PW | $33.6 \pm 0.70^{b}$ | $34.1 \pm 0.55^{b}$ | $32.3 \pm 0.74^{b}$ | $40.0 \pm 0.68^{a}$ | $41.2 \pm 0.66^{a}$ | *** |
| MC | $40.8 \pm 0.55^{b}$ | $40.5 \pm 0.43^{b}$ | $38.8 \pm 0.58^{b}$ | $44.6 \pm 0.53^{a}$ | $44.6 \pm 0.52^{a}$ | *** |
| EL | $18.6 \pm 0.35^{a}$ | $17.8 \pm 0.28^{ab}$ | $17.8 \pm 0.37^{ab}$ | $17.8 \pm 0.34^{ab}$ | $16.9 \pm 0.33^{b}$ | * |
| HL | $16.1 \pm 1.19^{a}$ | $14.6 \pm 0.93^{a}$ | $6.9 \pm 1.26^{b}$ | $16.2 \pm 1.15^{a}$ | $15.7 \pm 1.12^{a}$ | *** |
| CBL | $21.7 \pm 0.39^{c}$ | $20.8 \pm 0.30^{c}$ | $20.4 \pm 0.41^{c}$ | $28.6 \pm 0.38^{a}$ | $26.7 \pm 0.37^{b}$ | *** |

**Table 7.** Order of traits used in discriminating the cattle populations from different locations.

| Step | Variables entered | Partial R-Square | F value | Pr > F | Wilks' Lambda | Pr < Lambda |
|---|---|---|---|---|---|---|
| 1 | Cannon bone length | 0.7927 | 431.02 | < 0.0001 | 0.2073 | < 0.0001 |
| 2 | Horn length | 0.1445 | 19.00 | < 0.0001 | 0.1773 | < 0.0001 |
| 3 | Pelvic width | 0.1495 | 19.73 | < 0.0001 | 0.1508 | < 0.0001 |
| 4 | Body length | 0.1080 | 13.56 | < 0.0001 | 0.1345 | < 0.0001 |
| 5 | Ear length | 0.0884 | 10.83 | < 0.0001 | 0.1226 | < 0.0001 |
| 6 | Heart girth | 0.0436 | 5.08 | 0.0005 | 0.1173 | < 0.0001 |
| 7 | Height at withers | 0.0362 | 4.18 | 0.0025 | 0.1130 | < 0.0001 |
| 8 | Muzzle circumference | 0.0159 | 1.79 | 0.1290 | 0.1112 | < 0.0001 |

Figure 3. A: Representative Harar cattle bull; B: Representative Ogaden cattle cows. Photos: Amine Mustefa

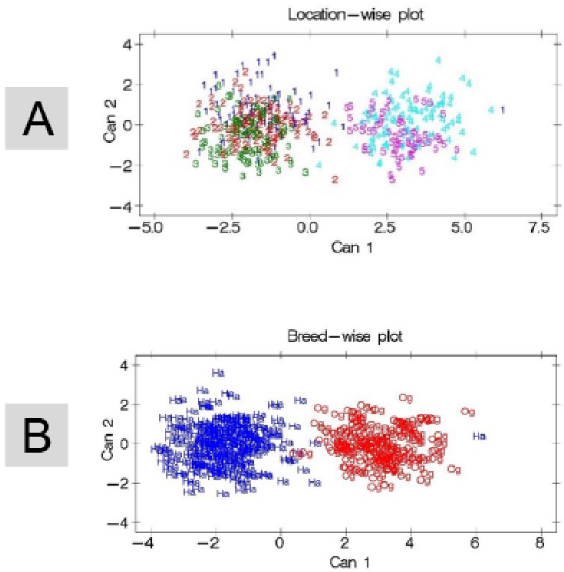


Figure 4. Location-wise (A) and breed-wise (B) plot of canonical discriminant analysis. Districts in A) are indicated by numbers: 1, Tulo; 2, Jarso; 3, Fedis; 4, Jigjiga; 5, Kebri Beyah. Breeds in B) are indicated by Ha, Harar and Og, Ogaden.

overall analysis shows medium (61%) classification of individuals into their corresponding location with an error rate of 39%. Furthermore, the highest (69.7%) classification of individuals into their location was observed in Kebri Beyah district while the lowest (45.6%) classifications were recorded in Jarso district.

Results of a breed-wise discriminant function analysis (Table 9) show the overall classification of individual animals into their breed. The overall analysis shows high (99%) classification of individuals into their corresponding breed with a small error rate of 1%. Furthermore, a higher (99.39%) classification of individuals into their breed was observed in Ogaden cattle than Harar cattle (98.63%).

Location-wise pairwise squared Mahalanobis distances are presented in Table 10. The distances were highly significant ($p < 0.0001$). The shortest distance (0.77) was obtained between Tulo and Jarso populations, while Fedis and Jigjiga populations were most distantly related (27.34). The breed-wise analysis also showed long Mahalanobis distance between the two breeds (22.15, $p < 0.0001$).

Location wise, multivariate statistics outputs showed the significance of Can 1 due to its high eigenvalue (5.3) and proportion (93%) to discriminate the cattle populations from the different locations. Can 2–Can 4 combined had only 7% proportion in discriminating the cattle populations with significantly low eigenvalue (0.37 combined). Similarly, Can 1 significantly discriminated the breeds during the breed-wise analysis with high eigenvalue (5.1) and 100% proportion. Therefore, the outputs of Can 1 are indicative and significant. Location-wise and breed-wise plot of the first two canonical variables to discriminate the cattle populations is presented in Figure 4. The cattle populations from Tulo, Jarso and Fedis districts were inseparable and in the same group; similarly, the populations from Jigjiga and Kebri Beyah districts were also inseparable and placed in the same group. However, those two groups were clearly separated from each other.

## Discussion

Qualitative morphological traits can help to easily differentiate breeds. The observed qualitative characteristic similarities among the cattle populations from Tulo, Jarso and Fedis districts support the presence of a unique cattle breed (the Harar cattle) in East and West Hararghe zones of Oromia region. This is also backed by the report of Rege and Tawa (1999), which stated the East and West Hararghe zones of Oromia region as the breeding tract of Harar cattle. Similarly, morphological similarities shared between the cattle populations from Jigjiga and Kebri Beyah districts and their variation from the previous group were also reported by Getachew *et al* (2014) who characterized them as Ogaden cattle. These qualitative results confirm the presence of two cattle breeds (Harar and Ogaden) in the eastern part of the country. In line with different publications including Mustefa *et al* (2021) on Raya cattle and Terefe *et al* (2015) on Mursi cattle, the results of the current study also confirm the existence of within-breed variations besides the between-breed differences.

The Ogaden cattle possess a relatively unique body colour compared to the Harar cattle, which has multiple body colours. The presence of multicolour (red, red +

**Table 8.** Number (and percent) of observations classified into locations.

| From district | Tulo | Jarso | Fedis | Jigjiga | Kebri Beyah | Total |
|---|---|---|---|---|---|---|
| Tulo | **54 (56.84)** | 27 (28.42) | 12 (12.63) | 1 (1.05) | 1 (1.05) | 95 (100) |
| Jarso | 28 (27.18) | **47 (45.63)** | 27 (26.21) | 0 | 1 (0.97) | 103 (100) |
| Fedis | 15 (15.79) | 17 (17.89) | **63 (66.32)** | 0 | 0 | 95 (100) |
| Jigjiga | 0 | 0 | 1 (1.03) | **64 (65.98)** | 32 (32.99) | 97 (100) |
| Kebri Beyah | 0 | 0 | 0 | 20 (30.30) | **46 (69.70)** | 66 (100) |
| Error rate | 0.4316 | 0.5437 | 0.3368 | 0.3402 | 0.3030 | 0.3911 |
| Priors | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | |

**Table 9.** Number (and percent) of observations classified bybreed.

| From breed | Harar | Ogaden | Total |
|---|---|---|---|
| Harar | 289 (98.63) | 4 (1.37) | 293 (100) |
| Ogaden | 1 (0.61) | 162 (99.39) | 163 (100) |
| Error rate | 0.0137 | 0.0061 | 0.0099 |
| Priors | 0.5 | 0.5 | |

**Table 10.** Pairwise squared Mahalanobis distances between locations. ***, $p < 0.0001$

| From District | Tulo | Jarso | Fedis | Jigjiga | Kebri Beyah |
|---|---|---|---|---|---|
| Tulo | 0 | - | - | - | - |
| Jarso | 0.77 *** | 0 | - | - | - |
| Fedis | 2.09 *** | 0.87 *** | 0 | - | - |
| Jigjiga | 22.17 *** | 24.13 *** | 27.34 *** | 0 | - |
| Kebri Beyah | 20.23 *** | 21.20 *** | 24.47 *** | 1.80 *** | 0 |

white, red + black, white + black, white, and grey) cattle in Harar might be due to the relatively highland-dominated areas of its distribution, especially the Tulo and Jarso districts. The frequently observed grey body in Ogaden cattle was due to the agropastoralists' preferences and selection of criteria for that particular coat colour (Getachew *et al*, 2014). Getachew *et al* (2014) also related the uniformly patterned grey body colour with their adaptation mechanism to the arid and semi-arid agroecologies of the Ogaden rangelands. This was in line with the report of Titto *et al* (2016), who reported animals with light coat colouring absorb less heat than those with darker coats.

Alongside the most observable qualitative characteristics, morphometric measurements can also produce more reliable information in characterizing and differentiating cattle breeds. The above grouping made by the qualitative characteristics of the cattle populations was also supported by the results of the quantitative measurements. Significantly higher values of heart girth, pelvic width, muzzle circumference and cannon bone length with shorter horns were observed in the Ogaden cattle (Jigjiga and Kebri Beyah districts) than in the Harar cattle.

Like for the qualitative results, within-breed variations were also observed in the morphometric measurements. Within Ogaden cattle, values of heart girth and pelvic width measurements were significantly higher for the population from Kebri Beyah district than Jigjiga district. These results made the population from Jigjiga district relatively closer to the Harar cattle. This might be due to the presence of mid- and high-altitude areas of Jigjiga district compared to the Kebri Beyah district, as well as the closeness in ground distance of the Jigjiga district to the distribution areas of Harar cattle.

In comparison to other Ethiopian indigenous cattle breeds, the morphometric measurements of both Harar and Ogaden breeds were found to be significantly lower than some lowland cattle breed like Begait cattle (Mulugeta, 2015). Similarly, body length, height at withers, ear length and horn length measurements of both breeds from the current study were lower than those of Raya cattle, while the reverse was true for heart girth and pelvic width measurements (Mustefa *et al*, 2021). Compared to the adjacent Afar cattle, the Ogaden cattle had higher values for height at withers and hearth girth while the Afar cattle had a longer body than both Harar and Ogaden cattle breeds (Tadesse *et al*, 2008).

The observed higher size-related linear body measurements of the males in each breed and location follow Rensch's rule (Rensch, 1950), which states that males are usually larger than females. Such differences between males and females might be due to the testosterone secreted in males which causes the growth of muscle mass and skeletal development (Baneh and Hafezian, 2009). Estrogen secreted in females has a limited effect on growth (Chriha and Ghadri, 2001; Baneh and Hafezian, 2009). The current results were comparable with the reports of Mustefa *et al* (2021) on Raya cattle, Terefe *et al* (2015) on Mursi cattle, and Genzebu *et al* (2012) on Arado cattle. Some size-linked morphological parameters (i.e. hump size and dewlap width) were also larger for males than females, as these traits are associated with the overall size of the cattle.

The morphometric variables, which discriminated the cattle populations, were ranked according to their importance. The inclusion of horn length within the top-three discriminatory variables is comparable with the reports of Mustefa *et al* (2021), who also classified it among the top-three variables to discriminate Raya cattle from other highland cattle breeds.

The high error rate of the discriminant function analysis among the different districts shows a lack of uniqueness within each location. On the contrary, some similarities were shared among locations. The cattle populations from Tulo, Jarso and Fedis districts shared similarities justifying their belonging to the same group (the Harar cattle group). Similarly, the cattle populations from Jigjiga and Kebri Beyah districts shared some similarities, which support their categorization into the same group (the Ogaden cattle group). This confirms the idea of previous studies which state the presence of Harar and Ogaden cattle breeds in the eastern part of Ethiopia (Rege and Tawa, 1999; Getachew *et al*, 2014; Mengesha, 2019). This grouping was also supported by the morphometric and morphological results of the current study.

The pairwise squared distance results between locations confirmed the already known differences between Harar and Ogaden cattle breeds, supporting the morphological, morphometric and multivariate results. However, these distances showed only the relative size differences between each population. Such differences might not necessarily be due to genetic differences (Zechner *et al*, 2001; Mustefa *et al*, 2021, 2022). Therefore, further diversity studies using molecular techniques are recommended to understand the level of genetic diversity within and between each breed.

In conclusion, two cattle breeds in Eastern Ethiopia listed under the FAO Domestic Animal Diversity Information System (DAD-IS), were phenotypically characterized to obtain and quantify the within- and among-breed diversity. Strong within-breed similarities and large between-breed differences (distance) were observed. Thus, the current study confirmed the presence of two cattle breeds (the Harar cattle and the Ogaden cattle) in Eastern Ethiopia. Besides breed differentiation, this study will be used to design conservation and genetic improvement programmes for each breed.

## Data availability

The data that has been used is confidential.

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## Conflict of interest statement

The authors declare that they have no conflict of interest.

## Author contributions

All authors contributed to the study conception and design. Material preparation and data collection were performed by Amine Mustefa, Tesfalem Aseged, Seble Sinkie, Fasil Getachew, Tesfu Fekensa, and Manaye Misganaw. Amine Mustefa performed the data analysis and wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript, and read and approved the final manuscript.

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