ORIGINAL ARTICLE

Morphological traits and structural indices of Hararghe highland goat populations reared in the West Hararghe zone, Ethiopia

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ABSTRACT

The study was conducted to describe the Hararghe highland goat populations based on their morphological traits and assess their type and function by applying structural indices. Nine qualitative and fifteen morphometric traits were collected from 450 goats (123 males and 327 females) in three agro-ecologies of the west Hararghe zone. Twenty-two structural indices were calculated from morphometric traits. The statistical analysis system's frequency and multiple correspondence analysis procedures were used to analyze qualitative data, while the general linear model procedures were used to analyze morphometric traits. The results indicated that the most frequently observed coat color pattern was mainly plain, followed by patchy. All the morphometric variables were significantly (p <0.05) affected by agro-ecology except body weight, scrotal circumference, rump width, and length. A strong positive correlation (p < 0.05) between body weight and other morphometric traits was observed for both sex groups. Most of the structural indices varied (p < 0.05) across the sex group and indicated that the Hararghe highland goat populations are suitable for meat production. This study revealed the presence of variability in the observed morphological traits among the studied goat populations in three agro-ecologies. Therefore, the Hararghe highland goat populations in this zone may possess unique adaptive features that are useful in designing sustainable goat genetic improvement programs. The genetic potential of Hararghe highland goat populations can be improved and maintained through community-based breeding programs for their sustainable utilization and conservation.

Keywords: agro-ecology, highland goat, morphometric trait, qualitative trait, structural index, west Hararghe zone

INTRODUCTION

Goats (*Capra hircus*) represent an important livestock component across all agro-ecological zones in sub-Saharan Africa (Chinchilla-Vargas et al., 2018). Goats contribute significantly to the livelihoods of resource-challenged farmers in Ethiopia (Hassen et al., 2012). It contributes meat, milk, skin, and fiber, as well as manure, and serves as the sole or subsidiary livelihood for a large number of small and marginal farmers and landless laborers (Thiruvenkadan and Karunanithi, 2006). In comparison to other ruminants, they have unique abilities to adapt and maintain themselves in harsh tropical environments (Mohammed et al., 2012).

In Ethiopia, small ruminants represent an important component of the farming system by providing about 12% of the value of livestock products consumed and 48% of the cash income generated at the farm level. They contribute to a quarter of domestic meat consumption, roughly half of domestic wool requirements, 40% of fresh skins, and 92% of the value of Ethiopia's semi-processed skin export trade (Assen and Aklilu, 2012). An estimated 3,982,556 goats are slaughtered annually in Ethiopia for domestic consumption (CSA, 2021). The goat population of Ethiopia is the second largest next to cattle, according to CSA (2021); the number of goats reported in the country is estimated to be about 52.5 million. With respect to breed, almost all of the goat populations are indigenous, which accounts for about 99.9% (CSA, 2021). These goat populations are phenotypically classified into 12 major distinct breeds and 5 additional sub-types (IBC, 2004). However, the recent genetic characterization revealed only the presence of seven distinctively different breeds in the country (Mekuriaw, 2016).

Appropriate design of breeding programs is impossible for breeds/types that have not been adequately characterized either morphologically or genetically (Mwacharo et al., 2006). Information on morphological characteristics is a vital prerequisite for sustainable improvement of any breed, utilization, and conservation (Melesse et al., 2013; 2022). This becomes imperative because uncontrolled mating and geographical overlap are leading to the endangerment of breed purity and potentially important reservoirs of goat genetic resources are being exposed at risk. The first step in the characterization of local genetic resources is to assess variations in morphological traits (Delgado et al., 2001; Melesse et al., 2022)).

In order to minimize the discrepancies of breed characterization, the "type" and "function" of livestock need to be assessed. This can be done using the ratios of some morphometrical measurements, giving rise to several indices popularly known as structural/ morphometrical/ zoometric indices (Banerjee, 2016). Calculations of structural indices can thus be useful tools for evaluating an animal's structural dimension and production function potential. These indices also help in enabling the selection of young and breeding animals and thus can assist in calculating the conformation of the animals, and the other advantage being that the values of the indices are not correlated with the age of the animals (Salako, 2006).

Goat types that are commonly reared in the Hararghe highland area are commonly known as Hararghe highland (HH) goats. The HH goat types are distributed in the East and West Hararghe zones of Ethiopia (Gizaw, 2009). In the west Hararghe zone, goats present the second largest population next to cattle (CSA, 2021), and goat meat is widely consumed and preferred over mutton. Moreover, the HH goats have a high preference among the producers because of their multipurpose contribution to their keepers. According to the author’s knowledge, there has not been a recent study carried out on the characterization of the goat genetic resources in three agro-ecologies of the West Hararghe zone based on their morphological traits. Moreover, no information is available on the assessment of the structural and functions of HH goats by applying structural indices. Therefore, this particular study was designed with two-fold objectives: firstly, to describe the HH goat populations based on their morphological characteristics; and secondly to assess their type and function by applying structural indices.

MATERIALS AND METHODS

Descriptions of the study area

The study was conducted in the west Hararghe zone of the Oromia National Regional State of Ethiopia. It is located between 7^{0}41'9" and 9^{0}14'27" N latitudes and 40^{0}9'41" and 41^{0}41'4" E longitudes. Its altitude ranges from 598 to 3079 meters above sea level. The west Hararghe zone was selected purposively for this study to address the HH goat breeds in different agro-ecological zones and farming systems. In this zone, about 85% of the population practice subsistence agriculture and livestock production. This area is characterized by three agro-ecological zones: highland, midland, and lowland, with the major farming systems implemented by the community being mixed, agro-pastoral, and pastoralist, respectively (ZARDO, 2017). The major livestock feed resources in the area were natural pasture, crop residues, fodder trees, and shrubs (Debela et al., 2017). The total livestock population in the zone is estimated to be about 2.64 million heads, of which 42% are goats (CSA, 2021).

Site selection and sampling strategy

In this study, a multistage sampling technique was applied to select representative samples from each stratum. In the first stage, three districts representing three agro-ecologies (low-, mid-, and highland) were purposefully chosen from the west Hararghe zone based on their goat production potential. In the second stage, two kebeles (the smallest administrative unit within the district) from each district were purposively selected based on the distribution of goat population size as compared with other livestock. In the third stage, households that owned at least three matured goats and had sufficient experience in rearing goats were identified within kebeles. One hundred fifty-six households were involved, i.e., 26 households in each kebele. Accordingly, 150 goats (115 females and 35 males) from lowland agro-ecology; 150 goats (103 females and 47 males) from highland agro-ecology; and 150 goats (109 females and 41 males) from midland agro-ecology with a total number of 450 were sampled, of which 327 and 123 were female and male goats, respectively. The owner's recall method, along with dentition classes (pairs of permanent incisors, PPI), was used to estimate the ages of goats. Thus, goats with 0PPI (milk teeth), 1PPI, 2PPI, 3PPI, and 4PPI were classified in the age groups of post-weaning, yearling, 2-year-old, 3-year-old, and 4-year-old, respectively (Ebert and Solaiman, 2010). Each animal was further identified by its sex, age, and sampling site.

Morphological trait data collection procedures

Qualitative traits

Qualitative traits are those characters that can be observed and recorded based on the breed morphological characteristics descriptor list of FAO (2012). It included data on coat color pattern, coat color type, hair coat type, head profile, ear orientation, presence and absence of wattle, beard, ruff, and horn.

Morphometric traits

Data were scored on 15 morphometric traits based on the FAO (2012) descriptor list. Accordingly, the following traits were measured: body weight (BW), heart girth (HG), withers height (HW), body length (BL), rump height (RH), paunch girth (PG), chest depth (CD), chest width (CW), sternum height (SH), rump width (RW), rump length (RL), head width (HDW), head length (HDL), fore cannon bone circumference (FC), and scrotum circumference (SC). All measurements were made using a plastic measuring tape, while the BW was taken using a suspended weighing scale with a 50 kg capacity. Goats were sampled early in the morning prior to sending them for grazing to avoid the effect of feeding and watering on the animal's size and conformation. All measurements were taken by the same person to avoid human error in each study site while the goats were in an up-right plane during measurement. Measurements were also restricted to healthy, non-pregnant, and non-castrated goats.

From the collected morphometric traits, 22 structural indices (Appendix Table 1) were calculated according to the methods suggested by Chacón et al. (2011), Khargharia et al. (2015), Banerjee et al. (2014), Barragán (2017), Dauda (2018), Abdurrahman and Dan (2017), and Salako (2006).

Statistical data analysis

Qualitative traits data were analyzed by using frequency and multiple correspondence analysis procedures of the Statistical Analysis Software System, while morphometric traits data were subjected to general linear model (GLM) procedures of the Statistical Analysis Software System (SAS, 2012, ver. 9.4) by fitting sex, age, agro-ecology, and sex by age interaction as fixed effects. When the F-test declared significant, multiple least-squares means were then compared with the Tukey-Kramer test. Pearson correlation coefficients were calculated to determine the degree of association between body weight and other morphometric traits. The model employed for analyses of body weight and other morphometric traits was:

$$\mathbf{Y_{ijkl} = \mu + A_i + S_j + B_k + A_i{*}S_j + e_{ijkl}}$$

Where: Y_{ijkl} = the observed l (body weight or other morphometric traits) in the ith age group, jth sex, and kth agro-ecology);

μ = overall mean,

A_i = the effect of ith age group (i = 0, 1, 2, 3 and 4) PPI

S_j = the effect of jth sex (j = female and male)

B_k = the effect of kth agro-ecology (k = lowland, midland, and highland)

$A_i{*}S_j$ = sex by age interaction effect

e_{ijkl} = random residual error

The model employed for the analysis of structural indices was:

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

Where: Y_{ij} = the calculated j (structural indices) in the ith sex;

μ = overall mean,

S_j = the effect of ith sex (i = female and male)

e_{ij} = random residual error

RESULTS AND DISCUSSION

Qualitative traits

The qualitative traits of HH goat populations reared in the west Hararghe zone are summarized in Table 1. The results of the study indicated that the HH goats were mainly characterized by a plain coat color pattern, followed by patchy and spotted. The coat color type of the HH goats found in the study area was brown (22%), then white-dominant (21.7%) and followed by white (18%) in females, while in males, white (26%) then brown-dominant (21.9%) and followed by white dominant (18.7%). The current study demonstrated that the HH goat populations have a wide range of coat color types, which is in good agreement with the findings of Gatew (2014), who reported a wide range of coat colors for the Bati, Borena, and short-eared Somali goat populations of Ethiopia. Similarly, Ofori et al. (2021) reported the presence of varied coat colors and patterns among the goat populations in the West African dwarf goat of Ghana.

The HH goat populations found in the study area were characterized dominantly by a short-haired smooth coat type. Wattles were observed in 11.4% of males and 6.73% of females. Ruffs occur in 70.7% of males but only (2.75%) in females. The results of this study were comparable with the report of Gatew

(2014), who reported that 68.89% of male Borena populations had ruffs but not in females. The ear orientation was erect, followed by semi-pendulous, pendulous, and was carried horizontally (Table 1). Beards were observed mainly in males. Most of the HH goats found in the study area were horned, while a few of them were polled

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Table 1. Qualitative traits of HH goat populations reared in the west Hararghe zone.

Traits	Attributes	Female		Male		Overall	
		N	%	N	%	N	%
Coat color pattern	Plain	184	56.3*	61	49.6*	245	54.4*
	Patchy	102	31.2	46	37.4	148	32.9
	Spotted	41	12.5	16	13	57	12.7
Coat color type	White	59	18.0	32	26*	91	20.2*
	Black	36	11.0	8	6.5	44	9.78
	Brown	72	22.0*	17	13.82	89	19.8
	Fawn	1	0.31	-	-	1	0.22
	Grey	10	3.06	3	2.44	13	2.89
	Roan	1	0.31	1	0.81	2	0.44
	White dominant	71	21.7	23	18.7*	94	20.9
	Black dominant	26	7.95	12	9.76	38	8.44
	Brown dominant	51	15.6	27	21.9	78	17.3
Hair coat type	Glossy	70	21.4	46	37.4	116	25.8
	Smooth hair	247	75.5*	77	62.6*	324	72.0*
	Long straight hair	1	0.31	-	-	1	0.22
	Curly rough	9	2.75	-	-	9	2.0
Wattles	Present	22	6.73	14	11.4	36	8.0
	Absent	305	93.3*	109	88.6*	414	92.0*
Ruff	Present	9	2.75	87	70.7*	96	21.3
	Absent	318	97.3*	36	29.3	354	78.7
Beard	Present	43	13.2	29	23.6	72	16.0
	Absent	284	86.8*	94	76.4*	378	84.0*
Head profile	Straight	104	31.8	30	24.4	134	29.9
	Concave	220	67.3*	89	72.4*	309	68.7*
	Convex	2	0.61	3	2.44	5	1.11
	Markedly convex	1	0.31	1	0.81	2	0.44
Ear orientation	Erect	210	64.2*	79	64.2	289	64.2*
	Semi pendulous	105	32.1	37	30.1	142	31.6
	Pendulous	9	2.75	6	4.88	15	3.33
	Carried horizontally	3	0.92	1	0.81	4	0.89
Horn presence	Present	274	83.8*	105	85.4*	379	84.2
	Absent	53	16.2	18	14.6	71	15.8

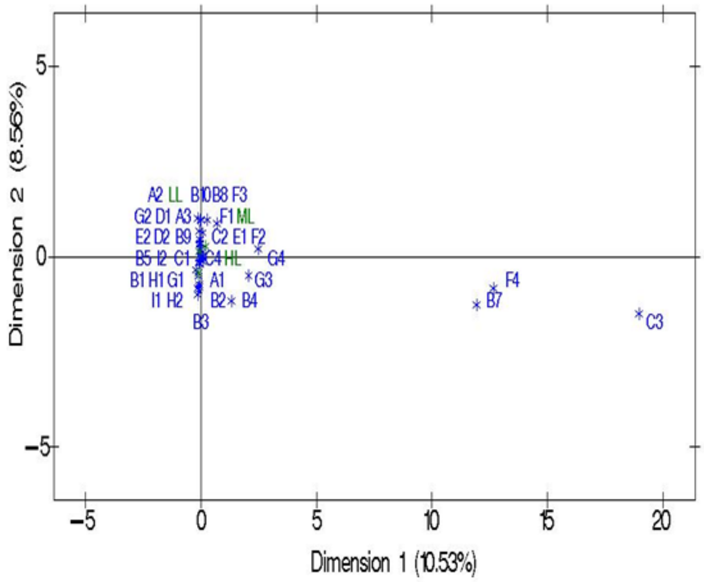
N = number of goat sampled; * = significant at ($p < 0.05$)

Multiple correspondence analysis

To understand the typical features of the HH goat population of each agro-ecology morphologically and transform them into a graphical display, multiple correspondence analyses were carried out on the recorded qualitative traits. Figure 1 shows a bi-dimensional graph representing the associations among the categories of the analyzed qualitative traits. The association is based on points found in approximately the same direction from the origin in the same region of space. From the figure, it can be shown that 19.09% of the total variations are explained by the first two dimensions (10.53% by the first and 8.56% by the second dimensions).

On the identified dimensions, the sample goat population in lowland agro-ecology was clustered together with white and grey coat color types, glossy hair coat types, no beard, concave head profile, and horned. The goat populations in highland agro-ecology were closely associated with patchy coat color patterns, smooth hair coat types, no ruff, white dominant coat color type, and concave head profile.

The goat populations in midland agro-ecology were closely black and had a dominant black coat color type, no wattles, straight head profile, and no ruff. Generally, on the identified dimensions, the goat population found in three agro-ecologies shared common qualitative traits. This indicates the existence of homogeneity among the studied goat populations.



Legends:	
Variables name	Levels and descriptions
Agro-ecology	LL = Lowland = Miesso; HL = Highland = Gemechis; M = midland = Doba
Coat color pattern (A)	A1=Plain, A2=Patchy, A3=Spotted
Coat color type (B)	B1=White, B2= Black, B3=Brown, B4=Fawn, B5=Grey, B6=Red, B7=Roan, B8=White dominant, B9=Black dominant, B10= Brown dominant
Hair coat type (C)	C1=Glossy, C2=Smooth hair, C3= Long straight hair, C4= Curly rough
Wattles (D)	D1=Present , D2=Absent
Ruff (E)	E1=Present, E2=Absent
Head profile (F)	F1=Straight, F2=Concave, F3=Convex, F4=Markedly convex
Ear orientation (G)	G1=Erect, G2=Semi-pendulous, G3=Pendulous, G4=Carried horizontally
Beard (H)	H1=Present, H2=Absent
Horn presence (I)	I1=Present, I2=Absent

Figure 1. Associations among qualitative traits categories via multiple correspondence analysis.

Morphometric traits

Knowledge of these morphometric traits is important to implement genetic improvement (selection), appreciate variations among goat populations to facilitate their sustainable use, and estimate body weight from simple and more easily measurable variables as well as market value in terms of the cost of the animals. The least squares means of body weight (kg) and other morphometric traits (cm) of HH goat populations by sex, age, agro-ecology, and sex by age group interaction effects are presented in Table 2. The results of the study indicated that RH was found to be higher than HW, indicating that the animal is sloppy. The findings are in close agreement with those of Khargharia et al. (2015). The coefficient of variation was found to be highest for the SC, which presented the maximum variation (17.1) followed by the BW (16.3), which suggests that genetic improvement of these traits through selection is possible. The coefficient of variation found in the present investigation is in harmony with the results of other studies in goats (Khargharia et al., 2015).

The HG, PG, CD, RW, RL, and HDW were different (p < 0.05) between the sexes. The influence of sex on the morphometric traits in the present study is likely related to sexual dimorphism, which leads to differential growth rates (Carneiro et al. 2010). Age had significant effects on all morphometric traits; when the goat age was increased, morphometric traits also increased. The current results are in agreement with those of Melesse et al. (2022), Yemane et al. (2020), Ahmed et al. (2016), and Takele (2014) for indigenous goats of Ethiopia, who reported that all body measurements increased as the age group increased. Similarly, Kurnianto et al. (2013) reported that most of the body dimensions of mature goats were higher than those of young goats, paralleling with the growth and development of morphometric traits of local goats in central Java, Indonesia. A linear increment of morphometric variables with age indicates a normal body development of goats, which suggests the suitability of the production environment for goat rearing (Melesse et al, 2022).

The results of the study further indicated that all the morphometric traits were affected (p < 0.05) by agro-ecology except BW, RW, RL, and SC. The difference in morphometric traits between agro-ecologies might have resulted from different management practices of the goat producers and the availability of feed resources (Melesse et al., 2013, 2022). Similarly, Loreto et al. (2015), Monau et al. (2018), and Getahun et al. (2020), reported that differences in agro-ecological zones could affect the morphometric traits of livestock caused by varied factors such as nutrition, grazing area, presence of disease, land size, productivity, availability of feed resources, and other natural resources in environmental and environmental conditions interactions. The interaction between sex and age significantly (p < 0.05) affected all the morphometric traits. The higher body weight of males than that of females at all ages is attributed to the aggressive behavior of males during feeding and sucking and the male sex hormone, which has an anabolic effect. Male goats outperformed their female counterparts in all age groups and measurements. This finding is consistent with Takele (2014), who reported that male goats have higher values than female goats across all age groups and measurements.

Correlation analysis between body weight and other morphometric traits

The correlations between body weight and other morphometric traits for female and male HH goat populations are presented in Table 3. The results revealed moderate to high, positive and significant correlations between body weight and other morphometric traits. This suggests that either of these morphometric traits or their combinations could provide a good estimate for predicting the body weight of HH goat populations. Further, it indicates that the morphometric traits increased as the body weight of the goat increased. Therefore, selection of one or more of these morphometric traits can lead to the improvement of body weight.

The findings of this study further showed a strong, positive, and significant correlation between body weight and HG, as well as between body weight and PG, implying that those variables could provide a good estimate in predicting body weight for the HH goat populations. From the morphometric traits, heart girth and paunch girth had the highest correlation with body weight in females (r = 0.94 and 0.92, respectively) and males (r = 0.91). The highest associations between heart girth and body weight was observed for male and female goat populations. The strong association of body weight with heart girth might be due to the relatively larger contribution of heart girth to body weight, which consists of bones, muscles, and viscera (Melesse et al., 2013). This finding is in agreement with those reported by Hassen et al. (2012) and Chinchilla-Vargas et al. (2018). Because morphometric traits, particularly heart and paunch girth, have a high correlation with body weight, they might be used as selection criteria in breeding strategies.

Scrotal circumference is the most heritable component of fertility that should be included for evaluation of breeding soundness (Mekasha, 2007). In this study, scrotal circumference exhibited a positive correlation ($p<0.05$) with body weight (r = 0.72). Similarly, Rahmani (2021) reported a good positive correlation between scrotal circumference and body weight (r = 0.88) in Ouled Djellal rams of Algeria. This may imply that because of the ease of measuring scrotal circumference, the HH goat can have the use of scrotal circumference as a selection criterion for future males for reproduction in natural control by choosing bucks with a large scrotal circumference.

Structural and functional indices

The structural and functional indices were calculated from the morphometric traits in order to assess the type and function of HH goats. Values of the structural and functional indices of HH goat populations are presented in Table 4. The cephalic index (IC) of HH goats was 67.3, and this is due to the fact that the head length of HH goats was larger than the width and they can be classified as dolichocephalous (long-headed). The body length is lower than the heart girth (IB = 85.8) and the IB value showed that the animals were medigline. They reported almost similar body indexes (85.29) and (86.87) in Cuban Creole and Assam Hill goats, respectively (Khargharia et al., 2015; Chacón et al., 2011), but lower than the reports of Dea et al. (2019).

The proportionality index value reported in this study is higher than those reported by Khargharia et al. (2015) and Chacón et al. (2011) for Assam Hill and Cuban Creole goats, respectively. Proportionality is an important index that correlates with good health and better disease resistance (Chacón et al., 2011). It also provides information about the length of the animal. The height at withers is greater than the body length and the proportionality index (108) was greater than 100, which indicates that the form of the animal tends to be square, characteristic of the dairy type.

The findings of the proportionality index (IPr, 108) correlates with the length index, as the height at the withers are slightly more than that of the body length due to taller shoulders. The longitudinal pelvic index (21.3) is not exceeding 37, which indicates that they are meat type animals. The pelvic index is used to determine the proportionality of the hindquarters and could be related to reproductive capability (Khargharia et al., 2015). The relative depth of the thorax index (36.3) is an indirect measure of leg length. The result DTI (11.9) is greater than 11 in those with a meat phenotype (hypermetric).

The findings pertaining to the thoracic development (TD) indicate that the heart girth is slightly higher than the height at withers. The TD value (1.07) is lower than the recommended value (1.2) for good thoracic development. The TD value from this study is similar to goats reared in the Aroresa district reported by Hankamo et al. (2020) and lower than reported for Boer buck by Chiemela et al. (2016). This could be an indication of thin and tall animals due to the high value of proportionality observed in this study.

Table 2. Least squares means of body weight (kg) and other morphometric traits (cm) of HH goat populations by sex, age, agro-ecology, and sex by age group interaction effects.

Effect and level	N	BW	HG	HW	BL	RH	PG	CD	CW	SH	RW	RL	HDW	HDL	FC	SC
Overall	450	25.1	66.6	61.8	57.1	64.2	79.8	21.8	15.5	39.3	16.8	13.8	9.39	14.0	7.87	21.4
CV%	450	16.3	5.62	6.31	6.85	5.79	6.64	8.63	12.8	9.04	7.39	8.2	6.98	5.58	3.77	17.1
Sex		NS	*	NS	NS	NS	*	*	NS	NS	*	*	*	NS	NS	
Female	327	24.8^{a}	67.2^{a}	61.7^{a}	57.2^{a}	65.1^{a}	81.4^{a}	21.9^{b}	15.5^{a}	39.5^{a}	17.1^{a}	14.1^{a}	9.46^{b}	14.2^{a}	7.90^{a}	-
Male	123	25.9^{a}	65.0^{b}	61.9^{a}	56.7^{b}	65.1^{a}	79.9^{b}	23.3^{a}	15.6^{a}	39.2^{a}	16.6^{b}	13.2^{b}	9.69^{a}	14.3^{a}	7.91^{a}	21.4
Age		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
0PPI	73	16.3^{e}	56.1^{e}	53.4^{d}	49.3^{e}	56.5^{d}	69.7^{e}	19.9^{c}	13.3^{d}	34.1^{d}	14.6^{d}	14.6^{d}	8.67^{e}	12.1^{e}	7.13^{d}	18.6^{c}
1PPI	114	22.3^{d}	64.1^{d}	60.4^{c}	54.3^{d}	63.8^{c}	78.4^{d}	22.1^{b}	15.1^{c}	38.6^{c}	16.2^{c}	16.2^{c}	9.27^{d}	13.9^{d}	7.92^{c}	22.8^{b}
2PPI	111	26.1^{c}	68.6^{c}	63.6^{b}	58.1^{c}	67.0^{b}	82.9^{c}	22.6^{b}	15.9^{b}	40.6^{b}	17.4^{b}	17.4^{b}	9.56^{c}	14.5^{c}	8.02^{b}	24.5^{a}
3PPI	71	29.1^{b}	70.7^{b}	64.7^{b}	60.8^{b}	67.7^{b}	85.4^{b}	23.5^{a}	16.1^{b}	40.7^{b}	17.8^{b}	17.8^{b}	9.94^{b}	14.9^{b}	8.09^{b}	25.7^{a}
4PPI	81	32.3^{a}	73.4^{a}	66.3^{a}	63.2^{a}	69.5^{a}	88.4^{a}	23.6^{a}	17.4^{a}	42.1^{a}	18.7^{a}	18.7^{a}	10.2^{a}	15.4^{a}	8.24^{a}	26.3^{a}
Agro-ecology		NS	*	*	*	*	*	*	*	*	NS	NS	*	*	*	NS
Lowland	150	24.7^{a}	66.2^{b}	62.7^{a}	58.3^{a}	66.4^{a}	80.5^{b}	22.1^{b}	15.8^{a}	40.3^{a}	17.1^{a}	13.9^{a}	9.64^{a}	14.2^{a}	7.89^{b}	21.6^{a}
Highland	150	25.9^{a}	68.1^{a}	63.4^{a}	56.6^{b}	65.5^{a}	82.5^{a}	22.9^{a}	15.9^{a}	40.3^{a}	17.1^{a}	13.8^{a}	9.61^{a}	14.6^{b}	8.04^{a}	22.9^{a}
Midland	150	24.7^{a}	65.5^{b}	59.3^{b}	56.3^{c}	62.2^{b}	79.9^{a}	22.0^{b}	14.9^{b}	37.6^{b}	16.9^{a}	13.7^{a}	9.32^{b}	13.8^{c}	7.79^{b}	21.6^{a}
Sex by age group		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Female, 0PPI	35	14.40^{h}	55.27^{h}	51.88^{h}	47.51^{g}	55.22^{h}	67.45^{h}	18.74^{f}	12.91^{f}	33.62^{e}	14.57^{f}	11.54^{f}	8.42^{f}	11.68^{h}	6.91^{e}	-
Female, 1PPI	63	19.82^{f}	63.06^{f}	59.14^{f}	52.82^{f}	62.61^{f}	76.95^{f}	20.85^{e}	14.55^{f}	38.09^{d}	16.04^{e}	13.01^{e}	9.09^{e}	13.61^{f}	7.92^{c}	-
Female, 2PPI	93	24.81^{e}	68.05^{d}	62.74^{e}	57.33^{d}	66.1^{de}	82.34^{d}	22.05^{d}	15.70^{d}	40.25^{c}	17.33^{c}	14.24^{d}	9.38^{e}	14.31^{e}	8.00^{c}	-
Female, 3PPI	61	28.00^{d}	72.29^{c}	63.86^{d}	60.29^{c}	66.85^{d}	84.83^{c}	23.14^{c}	15.88^{cd}	40.13^{c}	17.60^{c}	14.63^{c}	9.86^{d}	14.70^{d}	7.98^{c}	-
Female, 4PPI	75	31.37^{C}	73.08^{b}	65.72^{c}	62.73^{b}	68.98^{c}	88.02^{b}	23.33^{c}	17.29^{b}	41.97^{b}	18.61^{b}	15.46^{b}	10.4^{bc}	15.20^{c}	8.18^{b}	-
Male, 0PPI	38	18.07^{g}	56.94^{g}	54.89^{g}	50.94^{f}	57.76^{g}	71.81^{g}	21.00^{g}	13.76^{f}	34.63^{e}	14.71^{e}	11.63^{f}	8.89^{f}	12.52^{g}	7.34^{d}	18.63^{c}
Male, 1PPI	51	25.37^{F}	65.47^{e}	61.98^{e}	56.29^{e}	65.29^{e}	80.23^{e}	23.8^{c}	15.72^{d}	39.37^{c}	16.8^{d}	13.23^{e}	9.56^{e}	14.31^{e}	7.94^{c}	22.82^{b}
Male, 2PPI	20	32.72^{c}	71.44^{bc}	68.27^{b}	62.50^{b}	71.83^{b}	86.27^{bc}	25.72^{b}	16.68^{bc}	43.16^{b}	18.33^{b}	14.72^{cd}	10.50^{b}	15.66^{b}	8.16^{b}	24.50^{a}
Male, 3PPI	10	35.90^{b}	73.80^{b}	70.00^{b}	64.50^{b}	73.20^{b}	89.20^{b}	25.9^{ab}	17.90^{ab}	43.90^{b}	14.50^{b}	15.1^{bc}	10.4^{bc}	16.00^{b}	8.80^{a}	25.70^{a}
Male, 4PPI	6	44.16^{a}	78.50^{b}	73.83^{a}	69.83^{a}	77.00^{a}	93.66^{a}	27.33^{a}	19.00^{a}	47.33^{a}	20.83^{a}	6.50^{a}	12.33^{a}	17.66^{a}	9.00^{a}	26.33^{a}

[a,b,c,d] means with different superscripts within the same column and class are significantly different *($p < 0.05$); NS non-significant ($p > 0.05$); BW = body weight; HG = heart girth; HW = height at wither; BL = body length; RH=rump height; PG = paunch girth; CD = chest depth; CW = chest width; SH = sternum height; RW = rump width, R = rump length; HDW = head width; HDL = head length; FC = fore cannon circumference; SC = scrotal circumference; PPI = pair of permanent incisors; N = number of goat sampled; CV=coefficient of variation.

Table 3. Correlations between body weight and other morphometric traits of HH goat populations (above diagonal for female goat and below diagonal for male goat).

1	BW	HG	HW	BL	RH	PG	CD	CW	SH	RW	RL	HDW	HDL	FC
BW	1	0.94*	0.79*	0.87*	0.74*	0.92*	0.65*	0.61*	0.59*	0.78*	0.79*	0.61*	0.80*	0.66*
HG	0.91*	1	0.77*	0.87*	0.77*	0.97*	0.65*	0.66*	0.60*	0.78*	0.79*	0.61*	0.85*	0.71*
HW	0.85*	0.91*	1	0.87*	0.79*	0.78*	0.66*	0.52*	0.84*	0.66*	0.68*	0.54*	0.74*	0.64*
BL	0.89*	0.88*	0.87*	1	0.71*	0.76*	0.60*	0.58*	0.71*	0.71*	0.73*	0.55*	0.66*	0.56*
RH	0.85*	0.92*	0.98*	0.66*	1	0.78*	0.77*	0.54*	0.77*	0.64*	0.66*	0.51*	0.51*	0.64*
PG	0.91*	0.96*	0.89*	0.85*	0.88*	1	0.66*	0.61*	0.60*	0.60*	0.79*	0.60*	0.60*	0.72*
CD	0.85*	0.83*	0.79*	0.41*	0.78*	0.85*	1	0.47*	0.28*	0.55*	0.56*	0.55*	0.60*	0.47*
CW	0.70*	0.74*	0.70*	0.75*	0.70*	0.68*	0.64*	1	0.39*	0.57*	0.58*	0.43*	0.43*	0.42*
SH	0.74*	0.84*	0.88*	0.77*	0.88*	0.79*	0.62*	0.63*	1	0.51*	0.52*	0.37*	0.37*	0.52*
RW	0.83*	0.81*	0.78*	0.88*	0.79*	0.79*	0.72*	0.61*	0.63*	1	0.97*	0.59*	0.59*	0.64*
RL	0.79*	0.81*	0.79*	0.83*	0.80*	0.80*	0.71*	0.65*	0.76*	0.90*	1	0.57*	0.57*	0.64*
HDW	0.81*	0.77*	0.74*	0.71*	0.72*	0.76*	0.71*	0.60*	0.65*	0.67*	0.63*	1	0.71*	0.47*
HDL	0.86*	0.89*	0.85*	0.81*	0.84*	0.86*	0.80*	0.67*	0.77*	0.75*	0.74*	0.87*	1	0.47*
FC	0.76*	0.79*	0.77*	0.76*	0.76*	0.74*	0.67*	0.56*	0.68*	0.74*	0.72*	0.65*	0.79*	1
SC	0.72*	0.80*	0.78*	0.72*	0.80*	0.77*	0.66*	0.57*	0.79*	0.71*	0.72*	0.73*	0.73*	0.70*

BW = body weight; HG = heart girth; HW = height at wither; BL = body length; RH = rump height; PG = paunch girth; CD = chest depth; CW = chest width; SH = Sternum height; RW = rump width; RL = rump length; HDW = head width; HDL = head length; FC = fore cannon circumference; SC = scrotal circumference * = correlation is significantly different (p < 0.05), ^{NS} = correlation is non- significant (p > 0.05).

Table 4. Values (mean ± SE) of the structural and functional indices of Hararghe highland goat populations.

Indices	Male	Female	Overall
Cephalic index (IC)	68.3 ± 0.26^{a}	66.9 ± 0.25^{b}	67.3 ± 0.21
Body index (IB)	87.6 ± 0.42^{a}	85.1 ± 0.31^{b}	85.8 ± 0.26
Proportionality (IPr)	109 ± 0.53^{a}	108 ± 0.44^{a}	108 ± 0.35
Pelvic index (IP)	126 ± 0.63^{a}	122 ± 0.21^{b}	123 ± 0.24
Width slope (WS)	1.07 ± 0.01^{b}	1.11 ± 0.007^{a}	1.10 ± 0.01
Transverse pelvic (IPT)	25.6 ± 0.17^{b}	26.4 ± 0.11^{a}	26.2 ± 0.09
Longitudinal pelvic (IPL)	20.4 ± 0.14^{b}	21.6 ± 0.10^{a}	21.3 ± 0.08
Relative depth of thorax (RDT)	38.1 ± 0.23^{a}	35.60 ± 0.15^{b}	36.3 ± 0.14
Dactyl thorax index (DTI)	12.2 ± 0.07^{a}	11.8 ± 0.04^{b}	11.9 ± 0.04
Pectoral index (PI)	1.62 ± 0.008^{a}	1.61 ± 0.005^{a}	1.61 ± 0.004
Thoracic development (TD)	1.05 ± 0.003^{b}	1.09 ± 0.003^{a}	1.07 ± 0.002
Conformation index	68.4 ± 0.80^{b}	73.6 ± 0.54^{a}	72.1 ± 0.46
Depth index (DI)	0.38 ± 0.002^{a}	0.35 ± 0.001^{b}	0.36 ± 0.001
Length index (LI)	0.91 ± 0.003^{a}	0.92 ± 0.004^{a}	0.92 ± 0.002
Balance (B)	0.61 ± 0.007^{b}	0.71 ± 0.007^{a}	0.68 ± 0.006
Girth index (GI)	1.23 ± 0.004^{a}	1.21 ± 0.001^{b}	1.21 ± 0.001
Area index (AI)	3560 ± 69.6^{a}	3556 ± 33.4^{a}	3557 ± 30.8
Relative cannon thickness index	12.8 ± 0.08^{a}	12.8 ± 0.04^{a}	12.8 ± 0.04
Body weight index (BWI)	41.3 ± 0.72^{a}	39.8 ± 0.43^{a}	40.2 ± 0.37
Weight index	35.7 ± 1.11^{b}	39.1 ± 0.57^{a}	38.2 ± 0.51
Compact index	4.13 ± 0.07^{a}	3.98 ± 0.04^{a}	4.02 ± 0.03
Foreleg index (FLI)	38.4 ± 0.46^{b}	39.8 ± 0.22^{a}	39.4 ± 0.21

Different superscripts within a row denote significant differences at p<0.05 between sexes

For type assessment, indices derived from measurements more closely related to bone growth, such as foreleg length, height slope, and length indices, are more appropriate (Dauda, 2018). The length index (LI) indicates that the HH goat is longiline (>0.9) type. The LI value in the present study is lower than those reported by Khargharia et al. (2015) and Chacón et al. (2011) for Assam Hill (1.14) and Cuban Creole (1.07) goat, respectively. This variation in the LI could be due to breed differences and environmental factors. Relative cannon thickness (12.8) is higher in breeds with meat aptitude. The RCTI in the present study showed medium legs, which is important to grazing animals for browse in large areas with less difficulty. The body weight index (40.2) and weight index (38.2) indicate that the animals are medium in size. The compact index value of HH goats was 4.02 that classify them as meat type. This is in agreement with the findings of Yemane et al. (2020), who reported that the compact index value of goats was 4.06. The compact index value of male goats (4.13) was slightly higher than that of female goats (3.98), this shows that male goats more compacted than that of female goats. This is in agreement with the findings of Tade et al. (2021), who reported that male goats had higher compact index values than female goats.

The observations of the structural and functional indices indicated that most of the traits varied ($p < 0.05$) across the sexes. Similarly, Tade et al. (2021) reported that the effect of sex was significant for most of the structural indices of the indigenous goat populations of South Gondar, Ethiopia. The proportionality index value indicated that the HH goat is dairy type. However, the longitudinal pelvic, dactyl thorax index, relative cannon thickness, and compact indices exhibited that the HH goats are meat type. Therefore, the structural and functional indices analysis revealed that the Hararghe highland goat is hypermetric, robust, balanced, medium, and well adapted to the three agro-ecologies of the west Hararghe zone and suitable for meat production.

CONCLUSION

The study confirms that Hararghe highland goat populations are the predominant ecotypes in the study areas, with high preferences by the owners. The structural indices confirmed that the Hararghe highland goat is robust, balanced, medium, and well adapted in the west Hararghe zone's lowland, midland, and highland agro-ecologies and suitable for meat production. This study also revealed the presence of variability in the observed morphological traits among the goats studied in the three agro-ecologies. Therefore, the Hararghe highland goat populations in this zone may possess unique adaptive features that are useful in designing sustainable goat genetic improvement programs. Thus, the genetic potential of Hararghe highland goat populations can be improved and maintained through community-based breeding programs for their sustainable utilization and conservation.

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