Phenotypic Characterization of Indigenous Goats Population in Buldiglu District of Assosa Zone, Beneshangul Gumuz Region

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Abstract: An exploratory field study was conducted to phenotypically characterize the goat population in Buldiglu district, Asssosa Zone of Beneshangul Gumuz Region, Ethiopia. Data for qualitative and quantitative traits were collected from 630 randomly selected goats. The data was analyzed using the Generalized Linear Model procedures of SAS statistical software version 9.4. The result indicated that coat color types of indigenous goats are variable, and the most commonly observed coat color was white (36.34%), followed by white with different colors (red, brown, black, and fawn), uniform fawn, and gray coat color. The majority of the goat population has smooth hair (79.1%), and the remaining small proportion has long straight hair (9.4%), curly rough (6.4%), dull (3.8%), and glossy hair (1.9%). The most observed horn shapes for both sexes were straight (69.8%), curved (24.6%), and spiral (5.5%). The overall least square means of matured goat body weight, body length, heart girth, rump height, and height at withers were 29.48±0.22kg, 60.14±0.21cm, 71.70±0.20cm, 68.83±0.18 cm, and 67.45±0.19cm, respectively. The highest correlation coefficients of chest girth with body weight for female (r = 0.91) and male (r =0.93) goat populations demonstrated a strong association between these variables. The result of the multiple regression analysis showed that chest girth explained more variation than any other linear body measurements for does (81.4%) and bucks (87.7%). The prediction of body weight could be based on the regression equations for the female (y (body weight) =-41.7+0.98x (chest girth)) and male (y=49.6+1.10x) sample goat populations. This indicated that the heart girth alone to be the most important variable for predicting body weight in both sexes, and therefore the live body weight estimation, using only the heart girth would be better under extensive management conditions. The morphological variations obtained in this study could be complemented by performance data and molecular characterization using DNA markers to guide the overall conservation of goats and the formulation of appropriate breeding, selection, and conservation strategies.

Keywords: *Indigenous goats, Phenotypic characterization, Qualitative traits, Quantitative traits*

Introduction

Ethiopia has the largest livestock population in Africa and holds huge and diverse goat populations, which are kept in various production systems and different agroecological zones of highlands, semi-arid, and arid environments (IBC, 2004; Getnet, 2016). According to the CSA (2022), there are about 52.81 million goats in Ethiopia. Out of these, 69% are female, and the remaining 31% are male. Almost all the goats are indigenous breeds, which account for 100% of the total population (CSA, 2021). The sale of live goats and goat products (meat, skin, and milk) by farming communities are the major economic source for their subsistence (Hiwot *et al.*, 2020; Mezigebu *et al.,* 2022). Goats in Ethiopia play an important role in the livelihood of resource-poor farmers. In addition, goats are raised mostly to safeguard against crop failure and unfavorable crop prices in intensive cropping areas (Getahun and Girma, 2014). Resource-poor smallholder farmers and pastoralists manage almost all goat populations under traditional and extensive production systems (Solomon, 2014; Sisay *et al.,* 2022).

Despite existing huge and diverse goat populations, the productivity per unit of animal and the contribution of this sector to the national economy are relatively low. This is mainly due to inadequate works on breed and genetic improvement for the contributions of goats to the livelihoods of the poor, resulting in underutilization of the diverse goat genetic resources (Aziz, 2010). Understanding the existing small-scale goat keepers' diverse of management strategies (feeding, breeding, housing, watering, and health control) and the challenges they are facing enables to develop of effective intervention strategies (Tatek *et al.*, 2016). Thus, it is timely to improve indigenous goats low productivity to satisfy the increasing demand for animal protein, improve the livelihood of livestock keepers, and promote the economic development of the country at large.

Genetic improvement is among the existing methods to increase the productivity of the goat resource in the country. However, identification, characterization, and documentation of the breeds or strains and the type of environment in which they are kept, as well as a description of the breed characteristics, adaptation, and

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production potential in those environments, are required before beginning genetic improvement work (Mezigebu *et al.,* 2022; Sisay *et al.*, 2022). Moreover, to design improvement mechanisms, characterizing diverse goat breeds and populations, describing their external production characteristics in a given environment, managing them, and recognizing various constraints are critical (Hailu *et al.,* 2019). However, certain years back, goat research was limited in certain areas of Ethiopia due to a lack of manpower, limited budget allocation; and funds from donors (Halima *et al.,* 2012). These days, the Ethiopian government has given more consideration, and the scenario has been changing. As a result, different research activities (particularly phenotypic and genetic characterization) have been carried out in various parts of the country by various organizations and individuals (Halima *et al.,* 2012; Getnet*,* 2016; Hailu *et al.,* 2019; Oumer *et al.,* 2020; Wossene *et al.,* 2022).

Despite the investigation done, information on the morphological characteristics of different indigenous goat populations in their production environment is still scanty in the study area. The absence of adequate information on the characteristics of breeds potentially leads to wrong decisions and genetic erosion through crossbreeding, substitution, and dilution (Zewdu *et al.*, 2008). As a result, the present study was conducted to phenotypic characterization of the indigenous goat population under farmers' management conditions in the study area.

Materials and Methods

Description of the Study Area

This study was conducted in the Buldiglu district of Assosa zone, Western Ethiopia. The district is located at an altitude range of approximately 650-1140 m.a.s.l., with a uni-modal rainfall ranging between 900-1400 mm. The rainy season occurs from late April to November. A maximum and minimum temperature of the area were 22°C and 38°C, respectively (BDOA, 2022). It extends from 60 44` to 60 84` north latitude and from 370 92' to 380 6' east longitude. The district is located in the semi-arid agroecological zone. The livestock population of the district is estimated to be 7,043 cattle, 16,487 goats, 1,784 sheep, 3,717 equines, 28,204 chickens, and 9,808 honey bees (BDOA, 2022). The livestock population of 29604, of whom 15,282 were men and 14,322 were women and 5.8% of its population were urban dwellers. A mixed crop-livestock system is the dominant production system. Maize, sorghum, finger millet, teff, haricot bean, and sesame are among the crops produced in the area while goat, cattle, sheep, mule, donkey and poultry are the livestock species kept by the households (BDOA, 2022).

Sampling Techniques and Sample Size Determination

A purposive multi-stage sampling technique was used to identify the sample sites. Prior to the sampling of the study sites, a group discussion was made with livestock experts in Assosa Zone and districts within the zone. Based on the result of the discussion, one district (Buldiglu) was purposively selected based on the potential of the goat populations. After a rapid field survey and secondary information gathered from the key informants such as farmers' representatives/elders and livestock experts in the Bureau of Agriculture and Rural Development of the district, three PAs (Zumba, Derzahab, and Belanjaro) were selected based on goat population size, the presence of communal grazing areas, the relative significance of goats to the livelihood of the communities, access to market and road. In order to clarify the objectives and possible outcomes of the research, meetings were held with the communities at each selected peasant association. Sample goats from three peasant associations (PAs) were taken by using a simple random sampling method.

The sample size was determined by the formula for phenotypic characterization of livestock for a simple random sample by Cochran (1977) as FAO (2012) recommended. The following formula was used to determine the sample size:

$$n = \frac{z^2 * (p)(q)}{e^2},$$

where n = the minimum number of sample size within the range of acceptable error margin; Z^2 = standard normal deviation (1.96 for 95% confidence level); e = (acceptable error margin or precision, 0.03); p = (proportion of sampled population, 0.16) and q = (1-p) (estimate of the proportion of the population to be sampled, 0.84). The calculated number of households, following the proportional probability to size (PPS) sampling method was 180 (56, Zumba, 61, Derzahab, and 62, Belanjaro).

A total of 588 samples of goats were taken for the three kebeles from the Buldiglu. To increase the accuracy adding up to 10% of the sample size on this calculated sample is recommended and 7% of the sample size was added in this calculated sample. 588*7/100 =41.16, 588+41.16 =629.16= 630 goats used for collecting data from qualitative and quantitative traits. Based on the above formula, 630 goats (197 for Zumba, 215 for Derzahab, and 218 for Belanjaro kebeles), which had one and above pair of permanent incisors (1PPI) were used for body measurements and qualitative trait descriptions. Pregnant females and castrated males were not included in sample goats to avoid inaccuracy for body weight (BW) and linear body measurements (LBMs). Based on FAO (2012), from the total sample size, 75% of goats were females and the remaining 25% were males.

Methods of Data Collection

The survey data were collected from primary and secondary data sources. The qualitative and quantitative data were collected by individual measurement and observation. All data were recorded based on the breed morphological characteristics descriptor list of FAO (2012) for the phenotypic characterization of the goat. Data for quantitative traits heart girth (HG), body length (BL), wither height (WH), rump height (RH), chest depth (CD), shoulder width (SW), pelvic width (PW), ear length (EL), rump length (RL), rump width (RW), horn length (HoL), cannon bone length (CBL), cannon bone circumference (CBC) and head length (HL)) were measured using tailors measuring tape while BW was measured using suspended spring balance. Qualitative traits (coat color pattern, coat color type, horn presence shape, and orientation, ear orientation presence or absence of wattles, ruff, and bear through visual observations. For morphological traits characterization, goats were purposively grouped into 4 age categories based on dentition. These age groups were included with greater or equal to one pair of permanent incisors (≥1PPI), two pairs of permanent incisors (2PPI), three pairs of permanent incisors (3PPI) and four pairs of permanent incisors (4PPI) (Tatiana, 1999). Sex groups (male and female), health condition (healthy), and physiological state (lactating for females and un castrated for males) were also considered as selection criteria. Multiple linear regression equations were developed to predict the dependent variable (body weight) from different independent variables. A stepwise regression procedure was used to generate models (equations) for predicting male and female goat body weights separately from different linear body measurements. Best-fit prediction models had higher adjusted (R^2) values, which represent the percentage of total variability explained by the model, and smaller Mallow's parameters C(P) and mean square error (MSE).

Data Analysis

Different types of statistical analysis were used based on the nature of the data. For morphological characterization, all data gathered during the study period were coded and recorded. Both qualitative and quantitative data were analyzed using the Statistical Analysis System (SAS version 9.3, 2011). A chi-square ($\chi 2$) test was carried out to assess the statistical significance among categorical variables (qualitative variables). Multiple correspondence analyses were carried out for variables that were significant by $\chi 2$ and Fisher test to show the association among different categories of qualitative traits. The general linear model procedure (PROC GLM) of SAS was used to identify district, sex, and age group effects on quantitative traits. The effect of class variables was expressed as least square means (LSM±SE). When analysis of variance declares a significant difference, means were separated by using the adjusted Turkey-Kramer test. Both significant and non-significant values among fixed effects were discussed. The following statistical models were used to analyze body weight and other linear body measurements (LBM) except scrotal circumference (SC) for females:

$$y_{ijkl} = \mu + A_i + S_j + e_{ij},$$

Where: Y_{ijkl}= the observed l (body weight or LBMs) in the i^{th} age group and j^{th} sex; μ= overall mean; A_i = the effect of i^{th} age group ((i= 1PPI, 2PPI, 3PPI ≥4PPI); S_j= the effect of j^{th} sex (j = female or male) and e_{ij}= random residual error.

Multiple correlation was used to estimate the correlation between body weight and linear body measurements. The stepwise multiple linear regression analysis was conducted to obtain models for the estimation of live body weight from other linear body measurements for males and females within each age group using the stepwise procedure of SAS to determine the best-fitted regression equation for the prediction of body weight. Selection of variables at ($P<0.05$) was employed by incorporating all variables at the same time to see the order of selected variables and then stepwise regression analysis was made. The best-fitted model was selected based on the smaller value of the mallow's parameters C (P), mean square error (MSE), and the higher value of Adjusted R^2 and simplicity of measurement under field conditions to determine those traits that contribute much to response variables. For the multiple linear regression analysis, body weight is regressed on the body measurements separately for males and females (sex-specific), for each the following model was used.

Multiple linear regression models for females:

$$y_j = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + ej,$$

where: Yj = the dependent variable body weight; X1…. X7 = the independent variable; chest girth, body length, height at withers, tail length, horn length and ear length; β0 = the intercept; β1, β2,… β6 = the regression coefficient of the variable X1,X2 …… X6; and ej = the random residual error.

Multiple linear regression models for males:

$$y_j = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + \beta 7X7 + ej,$$

where: Yj = the dependent variable body weight; β0 = the intercept; X1…. X7 = the independent variable such as body length, heart girth, rump height; cannon bone length, chest width, head length and rump width, scrotum circumference, respectively; β1….β7= the regression coefficient of the variable X1,….X7; and ej = the residual error.

Results and Discussion

Qualitative Traits in Female and Male Goat Populations

The qualitative traits of indigenous goats found in the study district is summarized in (Table 1). The high chi-square test within and between goat populations indicated that the observed qualitative traits had significant differences ($p<0.05$) between goat populations for coat color pattern, coat color type, hair coat type, ear orientation, horn shape, and rump profile. However, there was no significant difference ($p>0.05$) in qualitative traits between horn orientation, wattle presence, back profile, head profile, beard presence, horn presence, wattle presence, back profile, and ruff presence. The study revealed that the overall coat color (Figure 1) patterns for both sexes were plain (63.1%) and patchy (27.7%). Higher proportions of plain and patchy coat color patterns were also previously reported for Woyito-Guji goats (Girma *et al.,* 2020). Oumer *et al.* (2020) also reported similar coat color patterns for Arab and Oromo goat breeds in Assosa districts, indicating that indigenous goats' populations share common coat color patterns, probably as a result of gene flow between these two neighboring populations. In contrast to this result, Gebreyowhens & Kumar (2017) reported that nearly half (42.3%) of the Maefur goat population in Tigray, Northern Ethiopia, had a spotty coat color pattern. On the other hand, different authors reported different coat color patterns. For instance, Halima *et al.* (2012) reported spotted and patchy patterns for the North Amhara goat population, while it was plain coat color patterns for Arsi-Bale goats (Belete *et al.,* 2015). In the current study, coat color types of indigenous goats are variable, and the most commonly observed coat color was white (36.34%), followed by white with different colors (red, brown, black, and fawn), uniform fawn, and gray coat color. In this study, the observed various coat color patterns and a wide range of coat color types in between goat populations might be due to a lack of systematic selection, which presents a chance for selection programs for breed improvement. Similarly, the studies of Belay and Meseretu (2017); Hailu *et al.* (2019), and Girma *et al.* (2020) reported that a wide range of coat colors existed for most goat populations in Ethiopia. The black coat color type was less frequently observed than other coat color types in both sexes. This indicates that farmers have a specific coat color preference in the study area. Unlike horn presence and horn orientation, the horn shape of the goat population had significant ($p<0.05$) differences. The majority of the goat population has smooth hair (79.1%), and the remaining small proportion has long straight hair (9.4%), curly rough (6.4%), dull (3.8%), and glossy hair (1.9%). The most observed horn shapes for both sexes were straight (69.8%), curved (24.6%), and spiral (5.5%). Similar results were also reported by Hulunim *et al.* (2017) indicated that straight (96.7%) and obliquely upward (10.2%) was dominant horn shape for Bati indigenous goat population in the South Wollo. Among the sampled goat population, the majority (72.3%) had ear orientation, which is carried horizontally, erect (18.6%), semi-pendulous (5.1%), and pendulous (4.4%). The majority of horizontal, lateral, and sideways ear orientations of goats were also previously reported for the North Shewa (Hailu *et al.* (2019) and Oromo (Oumer *et al.,* 2020) indigenous goat populations. The most frequent rump profile was flat (55.7%), while the remaining percentage was sloping (43.9%) and roofy (0.4%) in the study area. In contrast, Hailu *et al.* (2019) reported that the most frequent rump profiles were roofy (66.8%) for the indigenous goat population in the Northern Shewa Zone.

Quantitative Traits of Goat Population

Information on the body and other linear body measurements of specific goat breeds at constant age has paramount importance in the selection of genetically superior animals for production and reproduction purposes. In the study area, overall mean of live body weight, body length, heart girth, wither height, chest width, rump length, and rump height were 29.48±0.22kg, 60.14±0.21cm, 71.70±0.20cm, 67.45±0.19cm, 68.83±0.18cm, 14.62±0.10cm, 13.84±0.06cm and 14.80±0.10cm, respectively (Table 2).

Effect of sex on quantitative traits of goat: The least-squares means and standard errors for the effect of sex on body weight and other body measurements are indicated in Table 2. The least squares means showed that sex had a significant ($p<0.05$) effect on body weight and all body measurements. The values of males were higher ($p<0.05$) than females in body weight and all other linear body measurements. This might be due to hormonal effects, which are the release of androgen (which is known to have growth- and weight-stimulating effects) in male animals after the testes are well-developed (Wossene *et al.,* 2022). In this result, sex had a significant ($p<0.001$) effect on body measurements. As a result, as shown in Table 2, male goats were significantly longer in PW (pelvic Width), CBL (Cannon Bone Length), and CBC (Cannon Bone Circumference). However, body measurements between male and female goats were not significantly different in EL (Ear Length), HL (Horn Length), and TL (Tail Length) traits.

Effect of age groups on quantitative traits: The shape and size of the goat increase as the animal reaches maturity. Thus, age affects body weight and other body measurements of different goat breeds in Ethiopia (Minister *et al.,* 2019; Zewdu *et al.,* 2019; Girma *et al.,* 2020). In this study, body weight and all linear body measurements were significantly ($p<0.05$) different between ages (Table 2). Age groups of goats had a significant ($p<0.001$) effect on most of the body measurement traits of PW, EL, HL, TL, CBL, SC (scrotum Circumference), and CBC (Cannon Bone Length). Body weight and all other body measurements increased as the age of goats increased from the youngest (1PPI) to the oldest (4PPI). This indicated that as goat age increases, it increases in body weight and all linear body measurements. Results indicate that body weight and other leaner body measurements increase proportionately with the progression of age. This situation is, however, expected since the size and shape of animals change as age increases. This finding is consistent with the findings of Oumer *et al.* (2020) and Wossene *et al.* (2022), who noted that growth is a chronological process with inevitable consequences such as an increase in size and aging body weight, and that all body measurements increased as goats aged from the youngest (6 months) to the oldest (4 PPI) age group in goats. The existing heterogeneity within and between indigenous goats would provide the potential for future sustainable genetic improvement strategies through selection and proper utilization in the study area.

Table 1. Description of qualitative traits of the indigenous goat population in the study area.

Qualitative traits	Male	Female	Total Overall	$\chi 2$-value	Significance
	N (%)	N (%)	N (%)		
Coat color pattern					
Plain	85(47.2)	311(63.1)	397(63.1)	13.1	***
Patchy	52(43.4)	140(30.6)	175(27.7)		
Spotted	22(9.4)	36(6.3)	58(9.2)		
Coat color type					
White	50(20.8)	179(27.3)	229(36.34)		
Dark red	5(1.3)	22(3.82)	27(4.28)		
Black	1(0.00)	4(0.6)	6(0.95)		
Grey	6(1.8)	26(8.1)	32(5.07)		
Light red	11(7.5)	32(5)	43(6.8)		
Brown/fawn	13(15.1)	37(15.6)	50(7.93)		
Brown +white	20(9.4)	38(6.3)	58(9.7)	36.5	***
White +black	26(5.8)	52(10.19)	78(10.2)		
Black domain on white	14(13)	37(13.8)	51(7.93)		
White dominates in red	8(3.8)	19(3.1)	27(4.3)		
Red dominant on white	5(7.5)	24(5)	29(4.6)		
Hair coat type					
Glossy	3(1.9)	3(0.6)	6(1.9)		
Smooth hair	106(45.3)	296(73.8)	402(79.1)		
Straight long hair	19(26.4)	41(10.6)	60(9.4)	17.60	***
Curly rough	19(11.3)	25(9.4)	44(5.8)		
Dull	12(15.1)	12(5.6)	24 (3.8)		
Head profile					
Straight	112(73.5)	332(65.6)	444(70.4)		
Concave	45(22.6)	130(32.4)	175(27.8)	8.33	Ns
Convex	2(3.77)	9(2)	11(1.8)		
Markedly convex	0.00	0.00	0.00		
Beard					
Present	106(64.1)	141(33.1)	247(39.1)		
Absent	53(35.9)	330(66.9)	383(60.9)	9.16	Ns
Ear orientation					
Erect	46(37.7)	68(15.9)	114(18.6)		
Pendulous	4(3.8)	24(8.9)	28(4.4)	11.03	***
Semi-pendulous	9(3.8)	23(4.4)	32(5.1)		
Horizontal	100(54.9)	356(72)	456(72.3)		
Horn					
Present	143(84.9)	434(90.4)	577(91.6)		
Absent	16(15.1)	37(9.6)	53(8.4)	8.77	Ns
Horn shape					
Straight	101(52.8)	339(64.3)	440(69.8)		
Curved	45(37.7)	110(29.3)	155(24.6)	13.6	***
Spiral	13(9.5)	22(6.4)	35(5.5)		
Horn orientation					
Backward	133(84.9)	384(83.8)	517(80.9)		
Polled or stumps	13(11.3)	40(11.3)	53(8.9)	8.33	Ns
Obliquely upward	26(3.8)	53(5)	79 (10.2)		
Lateral	(0.00)	(0.00)	(0.00)		
Wattle					
Present	75(7.6)	62(5.1)	137(8.3)	9.36	Ns
Absent	142(92.4)	436(94.9)	578(91.7)		
Back profile					
Straight	117(68.8)	362(78)	479(76)		
Slopes toward rump	42(30.2)	101(19.5)	143(22.7)	3.6	Ns
Dipped	(0.00)	8(2.5)	8(1.3)		
Slopes toward wither	(0.00)	(0.00)	(0.00)		
Rump profile					
Slopping	79(41.5)	216(46.9)	293(46.9)	10.16	**
Flat	81(58.5)	256(53.1)	337(52.7)		
Roofy	0(0.00)	(0.00)	(0.00)		
Ruff					
Present	99(60.4)	7(3.8)	106(16.8)	2.45	Ns
Absent	60(39.6)	464(96.2)	524(83.2)		

***p<0.01; ***p<0.001; Ns= Non-significant.*

Figure 1. Indigenous goats in the study areas: doe (left) and buck (right).

Table 2. Least square mean (± SE) of body weight (kg) and other linear body measurements by sex and age.

Effect and level	N	Body weight	Body length	Heart girth	Wither height	Rump height	Chest width	Rump length	Rump width
		LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE
Overall mean	630	29.48±0.22	60.14±0.21	71.70±0.20	67.45±0.19	68.83±0.18	14.62±0.10	13.84±0.06	14.80±0.10
CV%	630	7.19	6.60	4.33	6.00	5.61	5.52	5.22	6.06
R^2	630	0.84	0.75	0.78	0.65	0.70	0.71	0.78	0.76
Sex:		***	***	***	***	***	***	***	***
Female	471	28.43±0.23^{b}	59.19±0.21^{b}	70.32±0.22^{b}	66.68±0.19^{b}	68.28±0.19^{b}	14.40±0.10^{b}	13.70±0.09^{b}	14.53±12^{b}
Male	159	31.52±0.48^{a}	63.14±0.36^{a}	74.50±0.34^{a}	68.90±0.38^{a}	70.01±0.37^{a}	15.35±0.14^{a}	14.30±0.11^{a}	15.83±0.16^{a}
Age:		***	***	***	***	***	***	***	***
1PPI	160	23.12±0.25^{d}	54.96±0.34^{d}	66.20±0.28^{d}	61.90±0.30^{d}	63.08±0.27^{d}	12.79±0.15^{d}	12.06±0.06^{d}	13.04±0.12^{d}
2PPI	110	27.03±0.29^{c}	58.14±0.40^{c}	69.36±0.32^{c}	65.22±0.34^{c}	67.68±0.30^{c}	14.30±0.12^{c}	13.16±0.11^{c}	14.32±0.13^{c}
3PPI	228	30.93±0.20^{b}	61.88±0.20^{b}	72.90±0.24^{b}	68.37±0.17^{b}	70.55±0.20^{b}	15.27±0.11^{b}	14.52±0.04^{b}	15.30±0.08^{b}
≥4PPI	132	35.23±0.30^{a}	65.10±0.37^{a}	76.20±0.32^{a}	70.61±0.22^{a}	72.88±0.24^{a}	16.52±0.14^{a}	15.41±0.09^{a}	16.67±0.11^{a}

Table 2. *Continued.*

Effect and level	N	Pelvic width	Ear length	Horn length	Tail length	Cannon bone length	Scrotum circumference	Cannon bone circumference
		LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE
Overall mean	630	13.97±0.07	13.27±0.06	13.34±0.04	13.15±0.16	8.02±0.06	23.88±0.16	13.18±0.07
R2	630	0.60	0.37	0.29	0.35	0.60	0.64	0.59
CV%	630	6.77	6.70	7.05	11.89	11.05	12.50	9.10
Sex:		***	Ns	Ns	Ns	***	-	***
Female	470	13.13±0.19^{b}	13.27±0.07^{ba}	13.29±0.05	13.04±0.13	7.87± 0.07^{b}	NA	12.96±0.07^{b}
Male	160	14.81±0.11^{a}	13.33±0.09^{a}	13.44±0.08	13.19±0.25	8.45±0.12^{a}	23.88±0.16	13.40±0.10^{a}
Age:		***	* **	***	***	***	***	***
1PPI	160	12.65±0.11^{d}	12.40±0.09^{d}	12.48±0.09^{d}	11.04±0.18^{d}	6.61±0.07^{d}	22.34±.014^{d}	11.50±0.11^{d}
2PPI	110	13.49±0.10^{c}	12.90^{c}±0.01^{c}	13.02±0.08^{c}	11.22±0.28^{c}	7.47±0.10^{c}	23.78±0.18^{c}	12.74±0.07^{c}
3PPI	228	14.46±0.08^{b}	13.95±0.08^{b}	13.81±0.05^{b}	13.03±0.18^{b}	8.66±0.08^{b}	25.27±0.022^{b}	13.71±0.08^{b}
≥4PPI	132	15.44±0.11^{d}	14.11±0.09^{ab}	14.12±0.09^{a}	13.78±0.23^{a}	9.45±0.10^{a}	26.47±0.23^{a}	14.16±0.10^{a}

*a, b, c, d = Means with different superscripts within the same column and class are significantly different; NS= Non-significant; *** significant at (p<0.001); CV= Coefficient of variation; 1PPI, 2PPI, 3PPI and ≥4PPI = 1, 2,3 and ≥4PPI pair of permanent incisors, respectively; N = Number of sample goat; NA= Not applicable.*

Correlation of Body Weight and Linear Body Measurements

The person correlation coefficient (r) obtained between live body weight and other liner body measurements of the sample goat population in the study areas is presented in (Table 3). Most of the quantitative traits had a significant (p<0.05) correlation with body weight in both male and female goats, except low positive correlations with ear length and horn length in female goats. In this study, a strong and significant (p<0.05) correlation was found between HG and BW observed during the study (r=0.93, 0.91) for male and female flocks, respectively. This implies that heart girth might be the best trait to estimate live body weight for indigenous goats and other livestock species. While cannon bone length (r=0.74, 0.78), cannon bone circumference (r=0.74, 0.66), and chest width (r=0.70, 0.88) had moderate/intermediate positive correlations enhance body weight or could be used to predict does live body weight for male and female flocks, respectively. The strong correlation of body weight with other linear body measurements indicated that these measurements could be used as indirect selection criteria to improve live body weight to predict or estimate body weight (Kassahun and Solomon*,* 2008). This indicated that either heart girth (for does and bucks) alone or a combination of these traits with other quantities of traits could be suggested as good estimators of live body weight for does and bucks. Similarly, different authors (Dereje *et al.*, 2019; Hailu *et al.,* 2019; Minister *et al.,* 2019; Zewdu *et al.,* 2019; Mezigebu *et al.,* 2022; Wossene *et al.,* 2022) observed the strongest and most positive correlation between body weight and heart girth of Ethiopian indigenous goats. The result indicated that trait preferences such as body weight and other linear body measurement narratives could used as input for designing improvement strategies for efficient utilization of the available genetic resources of goats.

Table 3: The coefficient of correlations between body weight and LBMs of indigenous goats (above diagonal for females and below diagonal for males) (N= 471 for females and N=159 for males).

	BW	HG	BL	HW	RH	RW	RL	CW	PW	HL	EL	TL	CBL	CBC
BW	1	0.91*	0.87*	0.84*	0.86*	0.79*	0.79*	0.76*	0.78*	0.58*	0.57*	0.59*	0.73*	0.74*
HG	0.93*	1	0.82*	0.82*	0.81*	0.77*	0.76*	0.71*	0.74*	0.48*	0.55*	0.53*	0.72*	0.73*
BL	0.89*	0.86*	1	0.75*	0.75*	0.72*	0.71*	0.70*	0.72*	0.53*	0.48*	0.52*	0.70*	0.68*
HW	0.87*	0.77*	0.76*	1	0.83*	0.67*	0.70*	0.66*	0.69*	0.44*	0.38*	0.49*	0.69*	0.66*
RH	0.81*	0.80*	0.78*	0.85*	1	0.74*	0.74*	0.64*	0.70*	0.36*	0.35*	0.41*	0.70*	0.68*
RW	0.87*	0.79*	0.64*	0.58*	0.58*	1	0.78*	0.72*	0.75*	0.36*	0.49*	0.51*	0.63*	0.65*
RL	0.82*	0.77*	0.67*	0.65*	0.66*	0.63*	1	0.71*	0.73*	0.30*	0.51*	0.53*	0.69*	0.63*
CW	0.86*	0.83*	0.56*	0.51*	0.48*	0.53*	0.55*	1	0.63*	0.49*	0.45*	0.48*	0.70*	0.69
PW	0.77*	0.69*	0.70*	0.63*	0.64*	0.73*	0.67*	0.53*	1	0.32*	0.38*	0.42*	0.66*	0.67*
HL	0.38*	0.33*	0.39*	0.48*	0.44*	0.68*	0.63*	0.55*	0.33*	1	0.37*	0.50*	0.71*	0.66*
EL	0.28*	0.31*	0.35*	0.22*	0.27*	0.25*	0.20*	0.28*	0.18*	0.28*	1	0.33*	0.56	0.60
TL	0.49*	0.44*	0.49*	0.45*	0.46*	0.43*	0.41*	0.40*	0.41*	0.47*	0.20*	1	0.56*	0.48*
CBL	0.56*	0.67*	0.59*	0.68*	0.69*	0.67*	0.63*	0.66*	0.46*	0.41*	0.18	0.48*	1	0.62*
CBC	0.66*	0.71*	0.69*	0.67*	0.65*	0.69*	0.67*	0.69*	0.56*	0.51*	0.21*	0.43*	0.58*	1
SC	0.83*	0.80*	0.76*	0.69*	0.70*	0.73*	0.71*	0.75*	0.69*	0.55*	0.28*	0.44*	0.66*	0.63*

BW= Body weight; HG= *Heart girth; BL= Body length; HW= Height at withers; PW= Pelvic width; HL= Horn length; EL= Ear length; SC= Scrotum circumference; RH= Rump height; CW= Chest width; RL= Rump length; RW= Rump width; CBL= Cannon bone length; TL= Tail length; CBC= Cannon bone circumference; * Correlation is significantly different (P<0.05).*

Prediction of Body Weight from other Liner Body Measurements (LBM)

The present result revealed that heart girth alone was the most important variable for predicting (or developing the mathematical equations) the body weight of does (Table 4) and bucks (Table 5), respectively. From the result of stepwise multiple regression analysis, the most important variable for predicting body weight was heart girth alone, compared to the other variables in both sexes in does (81.4%) and bucks (87.7%), especially in the Ethiopian context. This is in agreement with the results of Hailu *et.al.* (2019), and Oumer *et al.* (2020) who indicated that heart girth was selected as the best linear body measurement for prediction of the live body weight of animals. As we add other linear body measurements to heart girth, the value of R^2 (the proportion of the variance in the dependent variable that is predictable from the independent variable) for male goats increased (from 0.877 when heart girth alone to 0.918 when HG+BL) and the precision to estimate body weight increased. Similarly, the value of R2 increased from 0.814 when heart girth alone was added to 0.863 when HG+BL was added in female goats.

The present result revealed that heart girth alone was the most important variable for predicting (or developing the mathematical equations for predicting) the body weight of does and bucks, respectively. The most important variable for predicting body weight was the heart girth alone, compared to the other variables in both sexes in does (81.4%) and bucks (87.7%), especially in the Ethiopia context, respectively. This is consistent with the findings of Hailu *et al.* (2019) and Mezigebu *et al.* (2022), who found that heart girth was the best linear body measurement for predicting animal live body weight. The value of R^2 (the proportion of the variance in the dependent variable that is predictable from the independent variable) for male goats increased from 0.877 when heart girth alone to 0.918 when HG+BL) and the precision to estimate body weight increased. In female goats, the value of R^2 increased from 0.814 when heart girth alone was measured to 0.863 when HG and BL were added. Thus, the prediction of body weight could be based on the regression equations y = -41.7 + 0.98x for the female sample population and y = 49.6 + 1.10x for the male sample goat population; where, x and y are body weight and heart girth, respectively. Even though the increment of R^2 was small in each step in the model, a combination of more than one variable indicated that weight could be estimated more accurately by a combination of two or more variables. This may decrease the values of C (P) and MSE, which will ultimately increase the efficiency of the model. Even if the addition of more variables under on-farm conditions is unpractical due to increased cost and accuracy problems of the individuals taking measurements, especially in our country's context.

Table 4. Multiple regression analysis of live weight on different body measurements of does in all age groups.

Trait	Model	Parameters								Adj.R^2	R^2change	C(P)	MSE
		I	β_1	β_2	β_3	β_4	β_5	β_6	β_7				
BW	HG	-41.7	0.98							0.814	0.000	393.4	4.6
	HG + BL	-40.2	0.64	0.39						0.863	0.049	177.1	3.5
	HG + BL + RH	-47.1	0.48	0.32	0.32					0.884	0.021	82.2	2.9
	HG + BL + RH + RL	-44.9	0.41	0.28	0.29	0.40				0.894	0.010	37.1	2.6
	HG + BL + RH + RL + PW	-43.9	0.39	0.29	0.26	0.34	0.30			0.898	0.004	24.1	2.5
	HG + BL + RH + RL + PW + CBC	-42.1	0.38	0.28	0.25	0.31	0.26	0.21		0.900	0.002	17.2	2.4
	HG + BL + RH + RL + PW + CBC + CBL	-41.4	0.35	0.24	0.24	0.31	0.24	0.19	0.20	0.901	0.001	10.9	2.4

I= Intercept; BW= Body weight; HG= Heart girth; BL= Body length; CW= Chest width; RL= Rump length; RW= Rump width; CBL = Cannon bone length; SC= Scrotal circumference; Adj.R^2= Adjusted R-square; R^2= R-square; MSE= Mean square error; C(P)= Mallows C parameters.

Table 5. Multiple regression analysis of live weight on different body measurements of bucks in all age groups.

Trait	**Model**	**Parameters**									**Adj. R^2**	**R^2 change**	**C(P)**	**MSE**
		I	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8				
BW	HG	-49.6	1.10								0.877	0.000	150.6	4.7
	HG + BL	-47.8	0.73	0.40							0.918	0.041	71.5	3.6
	HG + BL + SC	-48.8	0.66	0.32	0.51						0.927	0.009	30.8	3.2
	HG + BL + SC + RL	-48.4	0.57	0.30	0.48	0.36					0.932	0.005	22.0	2.8
	HG + BL + SC + RH + CBL	-47.7	0.50	0.29	0.44	0.35	0.46				0.937	0.005	13.7	2.6
	HG + BL + SC + RH + CBL + RL	-49.5	0.49	0.29	0.42	0.34	0.44	0.26	23		0.938	0.001	11.2	2.4
	HG + BL + SC + RH +CBL+ RL + CW	-38.6	0.29	0.17	0.31	0.41	0.32	0.46	0.41		0.944	0.006	10.9	2.1
	HG + BL +SC + RH+CBL+ RL +CW+CBC	-35.4	0.27	0.16	0.23	0.36	0.25	0.33	0.32	.30	0.953	0.009	10.1	2.0

I=intercept, BW= Body weight, HG= Heart girth, BL= Body length, CW=chest width RL= Rump length, RW= Rump width, CBL = Cannon bone length; SC= Scrotal circumference, Adj.= Adjusted; R^2= R-square, MSE= Mean square error, C(P)= Mallows C parameters.

Conclusion

The result revealed the presence of phenotypic variations within the populations. In addition, the goats had shown different phenotypic characteristics with relative to the western lowland goat breed. A strong and significant correlation was found between HG (heart girth) and BW observed for male and female flocks. As a result, the most important variable for predicting body weight was HG alone, compared to the other variables. As body weight was highly predicted from heart girth, the latter can be used to estimate the former measurement in areas weighting scale is not available. The existing heterogeneity within and between indigenous goats would provide the potential for future sustainable genetic improvement strategies through selection and proper utilization in the study area. Furthermore, an investigation on molecular characterization using molecular markers like SNP could be suggested as supportive in high-resolution characterization, conservation, and formulation of breeding and selection strategies.

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Conflict of Interests

The authors declare that they have no competing interests.

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