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Research Article

Phenotypic characterization of indigenous goat population in North Wollo Zone, Amhara Region, Ethiopia

Yeshareg Taye[1,2], Mengistie Taye[1,3], Kefyalew Alemayehu[1], Zeleke Tesema[4]*

[1]College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia
[2]College of Agriculture, Woldia University, Woldia, Ethiopia
[3]Institute of Biotechnology, Bahir Dar University, Bahir Dar, Ethiopia
[4]Debre Birhan Agricultural Research Center, Debre Birhan, Ethiopia
***Corresponding author:** mengistietaye@gmail.com

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Abstract: *This study characterized indigenous goats in the North Wollo Zone, Amhara region, Ethiopia, focusing on their morphometric traits. A total of 550 goats (467 does and 83 bucks) were randomly selected for data collection, excluding pregnant and sick animals. Eight qualitative 19 (bucks) and 24 (does) linear body measurements were measured. Statistical analysis revealed that the agro-ecological zone, sex, and age significantly influenced both qualitative and quantitative traits. Highland goats, male goats, and older goats were generally larger. There was a positive and significant correlation between body weight and linear body measurements for both males and females. Among the body measurements, chest girth was identified as the best predictor of body weight, explaining more variation than other traits. These findings provide valuable insights into the morphometric characteristics of indigenous goats and can serve as a baseline for future research on goat breeding and management in the region. The study highlights the importance of understanding local goat populations to improve livestock management practices in smallholder systems.*

Keywords: Chest girth, Highland goats, Morphometric traits, Qualitative traits, Quantitative traits
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1. Introduction

Small ruminants have become steadily more important in the livestock production of rural households. This is due to farmers recognizing that small ruminants provide alternative opportunities to increase their incomes (Lohani, 2021). Ethiopia is a country that has a diversified livestock population in which goats and sheep has estimated to be 36.81 and 32.85 million, respectively (CSA, 2020). Measurements of various body conformations are of value in judging quantitative characteristics and help to develop suitable selection criteria. Moreover, the relative ease in measuring linear dimensions can be used as an indirect way to estimate the live weight (Getachew, 2008).

Despite the huge genetic diversity and valuable contributions of goats to the livelihoods of farmers in rural areas, the sector has been given low research and development attention at global and national levels (Abdel Aziz, 2010). Characterization study is very important to planning improvement, sustainable

utilization, and conservation strategies, mapping out an inventory of peculiar characteristics and for selection depending on the variation. However, in the absence of baseline characterization information, some breed populations and the unique characteristics they contain may decline significantly, or be lost, before their value is recognized and measures are taken to conserve them (FAO, 2007).

The characterization of local genetic resources is crucial for understanding the variation in their morphological traits, which is essential for classification based on size and shape (Agga et al., 2010). Previous studies on phenotypic characterization and farmers' preferences for goat traits have been conducted in various regions of Ethiopia (Hassen et al., 2012; Jeda & Asefa, 2016; Gatew et al., 2015; Adem, 2018). However, characterization studies became outdated due to changes in production systems and resulting changes in the trait preferences of the producers which in turn calls for updates. In line with this, there has been a lack of recent phenotypic characterization studies in the North Wollo Zone, Amhara Region. This gap has hindered the development of evidence-based strategies for local goat management and policy formulation. Therefore, this study aimed to provide updated phenotypic data on indigenous goats reared under smallholder systems in selected districts of North Wollo Zone. The research focused on both qualitative and quantitative traits to better understand the morphometric characteristics of these goats, offering valuable baseline information for future research and for the development of targeted initiatives and infrastructure in the region.

2. Materials and Methods

2.1. Description of the study area

The study was conducted in three purposively selected districts (Habru, Gubalafto, and Raya Kobo) of North Wollo Zone, Ethiopia (Figure 1). The study districts were selected in consultation with the north-Wollo zone livestock resource development representative office based on the potential of indigenous goats, the inclusiveness of the three agro-ecologies, farmers' goat production activities, and the economic contribution of goats in the household income in the areas. North Wollo zone is geographically located at 11°50′N 39°15′E and 11.833°N 39.250°E.

Agro-ecologically, north Wollo zone consists of lowland (500-1500 m a.s.l), midland (1500-2300 m a.s.l), and highland (2300-3200 m a.s.l). The agro-climatic characteristics of the study districts are presented in Table 1. The major crops grown in the study areas are cereals (maize, sorghum, teff, and wheat), pulses (peas and beans), and fruits (banana, papaya, orange, and mango). The main livestock species reared in the zone are goats, sheep, cattle, camel, and poultry (Woldia Town Administration, 2012). North Wollo zone has a livestock population of 612,440 goats, 1,087,072 cattle, 796906 sheep, 49421 horses, 17359 mules, 184192 donkeys, 34,265 camels, 2100202 poultry, and 132440 beehives (CSA, 17).

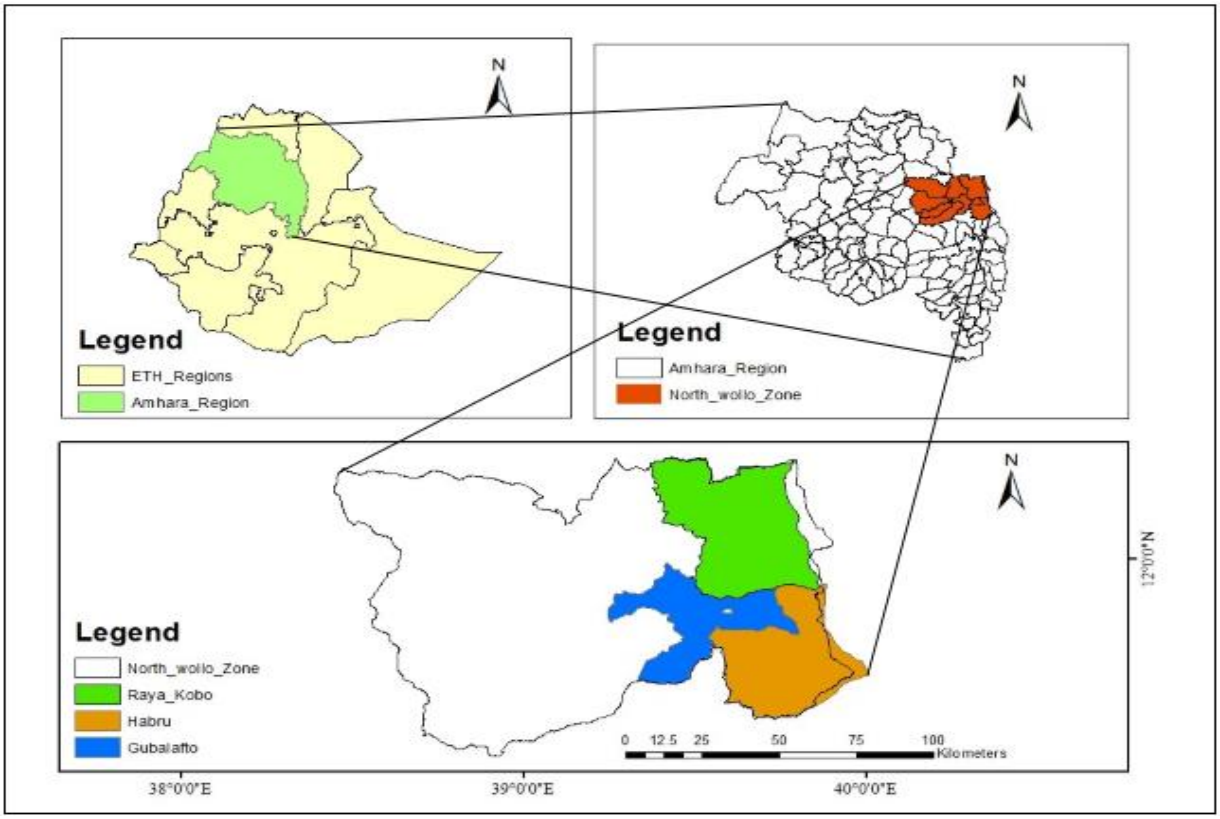

Figure 1: Geographical Location of the study area

Table 1: Description of study districts in North Wollo zone, Ethiopia

Study area characteristics	Habru	Gubalafto	Raya Kobo
Distance from Addis Ababa (km)	478	521	570
Distance from Bahir Dar (km)	390	360	410
Distance from Woldia (km)	30	0	50
Altitude range (m. a.s.l)	1200-2350	1600- 3300	1500 to 2200
Latitude and longitude	11035'N and 39° 38'E	9.11° and 14.59°N 36.31°and 39.81°E	12°09′N 39°38′E
Mean annual Rainfall (mm)	750 to 1000	777 to 1050	500-800
Mean max and min annual Tem (^{o}c)	28.5 and 15	22.28 and 7.5	12-33
Area (km^2)	470.2	918.3265	1852.6
Human population	203,274	168,414	228,798
Goat	69,296	47,237	128,068
Cattle	108,711	101,321	187,306
Sheep	26,717	60,857	47,591
Horse	NA	502	48
Donkey	10,695	18,785	21,691
Mule	430	945	552
Camel	10,578	2,351	19,407
Poultry	NA	101,716	185,411

Source: North Wollo zone livestock resource development representative office; NA: Not available

2.2. Sample size determination and sampling procedure

A rapid preliminary survey and discussion were held with zonal, district agricultural experts and development agents prior to the actual survey to locate the goat production potential of the areas. A purposive and simple random sampling technique was used to select the study areas and households and study animals. Based on this, three districts (Habru, Gubalafto, and Rayakobo) were selected purposively for the study based on the potential of the goat population. Then three kebeles from each district were selected through a purposive sampling procedure based on the goats' population potential and agro-ecologies. Finally, farmers who are rearing goats were selected for the interview through a random sampling method. The total sample size of goats for the measurement data was selected according to FAO (2012) guidelines. Therefore, for the current study, 83 males and 467 females with a total of 550 goats were selected and measured. The sample size of goats from each kebeles was selected randomly until the proportional sample size was reached after identifying which farmers have or have not kept goats as shown in Table 2.

In general, from North Wollo zone, three districts were purposively selected namely Habru, Gubalafto, and RayaKobo based on the goat population and from these districts, a total of nine kebeles were selected based on agro-cology and goat population. Accordingly, from each district, three kebeles with highland, midland, and lowland were selected. From Habru district, Merto, Wotie, and Keskebele; from Gubalafto district, Bekilomanekiya, Debot, and Sibilkay, and from RayaKobo district Dino, Gedeba and Aradum kebeles were selected. From these kebeles Merto, Bekilomanekiya, and Dino were for highland; Wotie, Debot, and Gedeba were for midland and Keskebele, Sibilkay, and Aradum were for lowland agro-ecologies. Households were selected using a random sampling technique; by identifying goat owners after proportional allocation of both households and sample.

Table 2: Proportional sampling of study goats in the study districts

Selected districts	Selected Kebeles	Goat population	Sample size
Habru	Metro (01)	415	9
	Wotie (08)	874	19
	Keskebele (030)	3200	69
Gubalafto	Beklomanekia (030)	405	9
	Debot (015)	650	14
	Sibilkay (03)	4256	91
Raya Kobo	Dino (025)	2614	56
	Gedeba (028)	5038	108
	Aradum (08)	8209	175
Total	9	25661	550

2.3. Data collection for qualitative and quantitative traits

Visual observation was made and morphological features were recorded based on the breed morphological characteristics descriptor list of FAO (2012) for phenotypic characterization of the goat. During data collection, each goat was identified by sex, age, and agro-ecologies. Dentition was used to estimate the approximate age of the goats. Qualitative traits such as coat color pattern, coat color type, head profile, presence/absence of wattle, horn orientation, horn shape, ear orientation, ear shape, and presence/absence of beard were recorded from selected samples (n = 550) goats.

Morphometric measurements were made on the quantitative traits of chest girth (CG), paunch girth (PG), chest depth (CD), wither height (WH), rump height (RH), rump length (RL), rump width (RW), head length (HL), head width (HW), body length (BL), ear length (EL), neck length (NL), neck

circumference (NC), sternum height (STH), horn length (HOL), cannon bone length (CBL), cannon bone circumference (CBC) and thigh circumference (TC) for both sexes and scrotum circumference (SC) for male goats. Figure 2 illustrates the process of measuring linear body dimensions. Measurements were taken on goats of age One Pair of Permanent Incisor (1 PPI) to 4 PPI for different anatomical points. Measurements were made in the morning before the animals left for grazing and after restraining and holding the animals in an unforced standing position. Pregnant and sick goats were not included in the sample for the purpose of avoiding errors. Quantitative traits were measured using tailors tape in centimeters while body weight was measured using a suspended spring balance (200 g precision).

Figure 2: Illustration of measuring quantitative traits. a) Body length; b) Body weight; and c) head width

2.4. Methods of data analysis

Qualitative traits data collected from the field was entered into SPSS (version 20) for coding and analysis by using simple descriptive statistics while quantitative data were entered into Microsoft Excel and exported to SAS (version 9.0) software for analysis. Correlation analysis was used to estimate the association between body weight and other linear body measurements for each sex using the Pearson correlation coefficient. A stepwise regression procedure was used to regress body weight using the PROC REG procedure of (SAS, 2004) to determine the best-fitted regression equation for the prediction of live body weight. The agro-ecology, sex and age of the goat were fitted as independent variables while body weight and linear body measurements were fitted as dependent variables. A general linear model of SAS was employed to identify the influence of independent variables on dependent variables. The statistical model used is presented below.

$$Yijkl = \mu + Ai + Cj + Sk + eijkl \quad [1]$$

Where Y_{ijkl} is the dependent variable, μ is overall mean, A_i is the effect of age, C_j is the effect of agro-ecology, S_k is the effect of sex, and e_{ijlk} is the residual error associated with each observation.

The statistical model for multiple regressions to analyze the body weight and other linear body measurements of female goats is presented below.

$$Yj = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \cdots .. \beta nXn + ej \quad [2]$$

Where:

Y_j = the response variable; live body weight

β_0 = the intercept

$X_1, \ldots, X_n$, are the explanatory variables (chest girth, paunch girth, rump length, thigh circumference, body length, height at wither, sternum height, and rump width)

$\beta_1, \ldots, \beta_n$ are regression coefficients of the variables $X_1, \ldots, X_n$

e_j = random error term associated with each observation

The statistical model for multiple regressions to analyze body weight and other linear body measurements of male goats;

$$Yj = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \cdots..\beta nXn + ej \quad [3]$$

Where:

Y_j = the response variable; live body weightβ_0=the intercept

β_0=the intercept

$X_1, \ldots, X_n$, are the explanatory variables (chest girth, body length, neck length, scrotum circumference, head length, head width, and rump width)

$\beta_1, \ldots, \beta_n$ are regression coefficients of the variables $X_1, \ldots, X_n$

e_j = random error term associated with each observation

3. Results and Discussion

3.1. Qualitative traits of indigenous goats

Qualitative traits are traits, which include the external physical form (shape, color, and appearance) of animals. These traits are recorded as discrete or categorical variables that are more directly correlated to adaptive traits. Qualitative traits are important for selection, especially for farmers to judge goats externally by their own selection criteria (Alemu, 2015). Generally, there is a difference in most of the qualitative traits between agro-ecology and sex as indicated in Table 3. The overall observed indigenous goat coat color pattern was plain (58.5%) followed by patchy (39.05) which indicated that spotted coat color goats were very limited in the area which accounts for 2.45%. This result was in line with the report of Adem (2018) who observed overall coat color patterns for both sexes were mainly plainly followed by patchy and spotted. In the area, farmers accept all coat color patterns except a black color. Black coat color goats with plain patterns were not preferred by respondents due to the amount of selling price and the perception of farmers. The current report was in line with the report of Alemu (2015) who reported that all goat keepers dislike black coat-colored goats in both sexes, especially in plain coat color type, and Hassen *et al*. (2012) who reported that goats with full black coat color is not preferred for slaughtering for home meat consumption in Ethiopia.

The major coat color types observed in the study area were red, red and white followed by light gray colors at 35.68, 19.17, and 15.33 %, respectively. In this study, about 99.93% of goats in the area did not have a wattle. In the area, 37 % of goats have a beard while the remaining 63% do have not a beard. However, a beard is mostly observed in male goats rather than females. The majority of goats (63.73%) in this area have a straight head profile followed by a convex (36.25%). In this study, about 73.43% of the goats have lateral ear orientation followed by semi-pendulous (21.73%) and pendulous (4.82%), respectively. Of all of the observed goats in the area, about 65.72% have a straight horn shape followed by spiral (34.25%). The orientation of the horn was backward, upward, and lateral with the overall percentage of 60.42, 39.03, and 0.55%, respectively.

The majority of goats in this area had strait horn shape (65.72%) with backward orientation (60.42%). This result was in line with the report of Adem (2018) who reported that the majority of goats have straight horn shape with backward orientations in Tach Gayint and Ebnat districts of south Gondar zone. In this study, most of the goats look like red and light gray as shown in Figure 3. Generally, agro-ecology has a significant effect ($P< 0.001$) on coat color pattern, coat color type, horn shape, horn orientation, and ear forms of the studied goats. However, wattle and head profiles were not affected by agro-ecologies in the area. Sex has a significant effect ($P< 0.01$) on beard, head profile, and horn orientation but, it had not a significant effect on coat color patterns, coat color types, and ear forms.

Figure 3: Illustration of qualitative trait characteristics of indigenous goats in north Wollo zone. a) Straight horn shape with backward orientation of doe; b) a spiral horn shape with back ward orientation of buck; and c) the most frequently observed coat color of goats (red) in the area

Table 3: The number of goats (N) and frequency (%) of qualitative traits of indigenous goat populations in north Wollo Zone, Ethiopia

Qualitative traits and Attributes	Highland		Midland		lowland		Overall Mean
	Male N (%)	Female N (%)	Male N (%)	Female N (%)	Male N (%)	Female N (%)	N (%)
Coat color pattern							
Plain	6(85.7)	21(31.3)	6(37.5)	65(52.0)	45(75.0)	191(69.5)	334(58.5)
Spotted	0(0.0)	3(4.5)	0(0.0)	2(1.6)	1(1.7)	19(6.9)	25(2.45)
Patchy	1(14.3)	43(64.2)	10(62.5)	58(46.4)	14(23.3)	65(23.6)	191(39.05)
χ^2, within agro-ecology							51.85^{**}
χ^2, within sex							4.01^{NS}
Coat color type							
White	3(42.9)	7(10.4)	0(0.0)	8(6.4)	3(5)	7(2.5)	28(11.2)
Black	1(14.3)	1(1.5)	4(25)	12(9.6)	0(0.0)	1(0.4)	19(8.45)
Red	2(28.6)	13(19.4)	2(12.5)	41(32.8)	33(55)	181(65.8)	272(35.68)
Roan	0(0.0)	0(0.0)	0(0.0)	2(1.6)	6(10)	5(1.8)	13(2.23)
Light gray	1(14.3)	15(22.4)	0(0.0)	35(28)	11(18.3)	33(12)	95(15.83)
Brown	0(0.0)	0(0.0)	0(0.0)	6(4.8)	2(3.3)	3(1.1)	11(1.53)
Red and white	0(0.0)	23(34.3)	8(50)	13(10.4)	5(8.3)	33(12)	82(19.17)
Red and black	0(0.0)	3(4.5)	0(0.0)	4(3.2)	0(0.0)	8(2.9)	15(1.77)
White and black	0(0.0)	5(7.5)	2(12.5)	4(3.2)	0(0.0)	4(1.5)	15(4.12)
χ^2, within agro-ecology							128.35^{**}
χ^2, within sex							16.27^{NS}
Wattles							
Present	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	1(0.4)	1(0.06)
Absent	7(100)	67(100)	16(100)	125(100)	60(100)	274 (99.6)	549(99.9)
χ^2, within agro-ecology							0.64^{NS}
χ^2, within sex							0.17^{NS}
Beard							
Present	4(57.1)	6(9.0)	12(75)	4(3.2)	39(65.0)	29(10.5)	93(37)
Absent	3(42.9)	61(91)	4(25)	121(96.8)	21(35.0)	246(89.5)	457(63)
χ^2, within agro-ecology							6.38^{*}

Qualitative traits and Attributes	Highland		Midland		lowland		Overall Mean
	Male N (%)	Female N (%)	Male N (%)	Female N (%)	Male N (%)	Female N (%)	N (%)
χ^2, within sex							166.8**
Head profile							
Straight	1(14.3)	57(85.1)	10(62.5)	113(90.4)	25(41.7)	243(88.4)	449(63.73)
Concave	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Convex	6(85.7)	10(14.9)	6(37.5)	12(9.6)	35(58.3)	32(11.6)	101(36.25)
χ^2, within agro-ecology							4.06 NS
χ^2, within sex							95.46**
Ear form							
Lateral	7(100)	41(61.2)	16(100)	102(81.6)	24(40)	159(57.8)	349 (73.43)
Pendulous	0(0.0)	2(3)	0(0.0)	2(1.6)	10(16.7)	21(7.6)	35(4.82)
Semi-pendulous	0(0.0)	24(35.8)	0(0.0)	21(16.8)	26(43.3)	95(34.5)	166(21.73)
χ^2, within agro-ecology							39.56**
χ^2, within sex							5.72NS
Horn shape							
Straight	7(100)	60(89.6)	6(37.5)	68(54.4)	33(55.0)	159(57.8)	333(65.72)
Spiral	0(0.0)	7(10.4)	10(62.5)	57(45.6)	27(45.0)	116(42.2)	217(34.25)
χ^2, within agro-ecology							33.17**
χ^2, within sex							1.074 *
Horn orientation							
Lateral	0(0.0)	0(0.0)	0(0.0)	0(0.0)	2(3.3)	0(0.0)	2(0.55)
Upward	4(57.1)	16(23.9)	4(25)	76(60.8)	4(6.7)	167(60.7)	271(39.03)
Backward	3(42.9)	51(76.1)	12(75)	49(39.2)	54(90)	108(39.3)	277(60.42)
χ^2, within agro-ecology							19.714**
χ^2, within sex							56.14**

* = significant at P ≤0.05, ** = significant at P≤0.001, NS = not significant

3.2. Body weight and morphometric traits of goats

The least - square mean (LSM±SE) of body weight and other linear body measurements of indigenous goats is presented in Table 4. The overall least-square means of BWT, BL, WH, CG, CW, RL, and HOL of indigenous goat populations were 31.07±0.29 kg, 60.39±0.24 cm, 66.05±0.19 cm, 73.2±0.29 cm, 16.23±0.11 cm, 14.47±0.06 cm, and 12.53±0.16 cm, respectively. This report was comparable with the report of Zergaw *et al*. (2016) who noted that the least-square means of quantitative traits like body weight, body length, height at wither, chest girth, chest width, ramp length, horn length, ear length and pelvic width of central highland goats was 29.5 ± 0.2 kg, 62.2 ± 0.2, 67.5 ± 0.2, 72.9 ± 0.2, 13.4 ± 0.1, 19.7 ± 0.1, 12.8 ± 0.2, 14.6 ± 0.1 and 13.5 ± 0.1 cm, respectively. The other body measurements of STH, CBC, CBL, CD, RH, RW, PG, and SC, etc. were measured as 43.34±0.17, 8±0.04, 9.7±0.05, 42.81±0.20, 68.72±0.17, 12±0.07, 77.14±0.90, 22.2±0.33cm, respectively.

The fixed effect of sex (P<0.05), age (P<0.01), and agro-ecology (P≤0.05) significantly affected most of the traits considered. Generally, goats in the highland agro-ecology performed better in traits such as BW, BL, CG, CD, and PG as compared to midland and lowland agro-ecology which were similar in most of the measurements. In most of the quantitative traits, age groups of 3PPI and 4PPI had similar performances. The current finding was in agreement with the report of Tadesse *et al*. (2015).

In this study, male and female goats did not show a significant difference (P≥0.05) in (RH, STH, and NL) however, female goats showed higher value (P<0.01) in body weight, and most of the linear body measurements (RL, RW, CG, CW, CD, BL). This

might be due to the reason that sample male goats were younger (majorly aged between 1 and 2 years old) since farmers sold male goats above two years at any time when cash is needed. However, this result did not agree with the report of Adem (2018) and Alemu (2015) that males were larger in body weight and other linear body measurements than their female counterparts.

3.3. Correlation between body weight and linear body measurements

The coefficient of correlations between body weight and linear body measurements (LBMs) of indigenous goats in the study area is shown in Table 5. Determining animal live body weight, linear body measurement, and their relationship are very important for determining genetic potential, breed standards, and improved breeding programs for higher meat production (Younas *et al*., 2013). In this study, positive and strong associations were observed between body weight and chest girth (r = 0.9 for male, r = 0.8 for female), wither height (r = 0.8 for male, r = 0.7 for female), body length (r = 0.8 for male, r =0.7 for female), rump length (r = 0.7 for male, 0.7 for female), paunch girth (r = 0.8 for male, r = 0.8 for female). In this study, chest girth was the best predictor variable which accounts for the correlation coefficient of 0.9 and 0.8 for males and females, respectively. This suggests that chest girth alone could provide a good estimate for predicting live body weight of indigenous goat populations. This report was in line with many researchers (Gebreyesus *et al*., 2012; Dawit, 2012; Seid, 2013; Alemu, 2018; Tesfahun, 2013).

Generally, all linear body measurements showed highly significant associations (P = 0.01) with body weight positively both in male and female goats. While scrotum circumference has a significant association (P = 0.05), this shows that as the value of linear measurements increases the body weight also increases. The current finding was in line with the previous reports (Hassen *et al*., 2012; Assefa, 2013; Adem, 2018), that there was a positive and high correlation between body weights with other linear body measurements.

Table 4: Body weight (kg) and linear body measurements (cm) with fixed factors of sex, age and agro-ecologies of goats in north Wollo zone, Amhara region, Ethiopia

Effects and level	N	Body weight	Body Length	Wither Height	Sternum height	Cannon bone circumference	Cannon bone length	Chest girth	Chest width	Chest depth
		LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE
Overall mean	550	31.07±0.29	60.39±0.24	66.05±0.19	43.34±0.17	8±0.04	9.7±0.05	73.2±0.29	16.23±0.11	42.81±0.20
CV (%)	550	15.8	7.21	5.7	8.8	9.45	9.9	6.7	13.9	9.57
R^2	550	0.5	0.38	0.34	0.11	0.19	0.17	0.5	0.19	0.27
Sex		**	**	**	NS	**	**	**	**	**
Male	83	29.51±0.92^{b}	59.78±0.72^{b}	68±0.59^{a}	43.1±0.48	8.54±0.14^{a}	10.18±0.11^{a}	70.72±0.84^{b}	15.2±0.39^{b}	41.65±0.69^{b}
Female	467	31.34±0.30^{a}	60.49±0.24^{a}	65.71±0.20^{b}	43.38±0.18	7.9±0.03^{b}	9.59±0.04^{b}	73.64±0.30^{a}	16.40±0.10^{a}	43.01±0.20^{a}
Age group		**	**	**	**	**	**	**	**	**
1PPI	155	25.34±0.32^{c}	56.41±0.32^{c}	63.22±0.33^{c}	41.93±0.30^{b}	7.78±0.06^{b}	9.24±0.07^{b}	67.39±0.37^{c}	14.71±0.18^{c}	40.38±0.38^{c}
2PPI	135	29.24±0.42^{b}	58.53±0.39^{b}	65.40±0.29^{b}	42.95±0.29^{b}	7.88±0.05^{b}	9.76±0.09^{a}	71.18±0.44^{b}	16.16±0.18^{b}	42.20±0.39^{b}
3PPI	139	34.76±0.49^{a}	63.35±0.34^{a}	67.97±0.30^{a}	44.48±0.32^{a}	8.17±0.07^{a}	9.84±0.08^{a}	77.60±0.46^{a}	17.27±0.19^{a}	45.66±0.39^{a}
4PPI	121	36.19±0.58^{a}	64.15±0.40^{a}	68.21±0.47^{a}	44.29±0.40^{a}	8.20±0.09^{a}	10±0.10^{a}	77.84±0.46^{a}	17.04±0.21^{a}	43.32±0.30^{b}
Agro ecology		**	*	**	**	*	*	**	*	**
Highland	74	34.32±0.89^{a}	62.24±0.81	66.99±0.46	44.99±0.49^{a}	7.91±0.08^{ab}	9.60±0.09^{ab}	75.43±0.92^{a}	16.8±0.25^{b}	46.05±0.54^{a}
Midland	141	30.29±0.5^{b}	60.33±0.41	65.80±0.35	42.95±0.32^{b}	7.83±0.07^{b}	9.48±0.08^{b}	73.01±0.44^{b}	15.9±0.15^{a}	43.35±0.37^{b}
Lowland	335	30.67±0.37^{b}	60.22±0.3	65.06±0.27	43.15±0.22^{b}	8.09±0.05^{a}	9.8±0.06^{a}	72.8±0.38^{b}	16.25±0.15^{ab}	41.9±0.25^{c}

Continued from Table 4

Effects and level		Rump height,	Rump length	Rump width	Paunch girth	Head length	Horn length	Head width	TC	NC	Neck length	SC
	N	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE
Overall mean	550	68.72±0.17	14.47±0.06	12±0.07	77.14±0.90	20.07±0.10	12.53±0.16	17.1±0.08	19.6±0.13	30.46±0.16	22.65±0.12	22.2±0.33
CV (%)	550	5.09	8.13	10.43	7.64	11.09	22.96	9.36	14.14	10.53	11.77	12.38
R^2	550	0.26	0.35	0.4	0.47	0.15	0.43	0.177	0.13	0.28	0.13	0.22
Sex		NS	*	**	**	**	**	**	**	**	NS	NS
Male	83	68.98±0.51	13.97±0.19^{b}	10.66±0.2^{b}	72.43±0.89^{b}	20.71±0.26^{a}	13.54±0.52^{a}	18.34±0.24^{a}	20.66±0.35^{a}	33.09±0.64^{a}	22.37±0.44	22.20±0.33
Female	467	68.67±0.18	14.56±0.06^{a}	12.24±0.06^{a}	77.97±0.36^{a}	19.95±0.11^{b}	12.35±0.17^{b}	16.88±0.07^{b}	19.41±0.13^{b}	29.99±0.14^{b}	22.70±0.11	Na
Age group		**	**	**	**	**	**	**	**	**	**	*
1PPI	155	66.16±0.25^{c}	13.44±0.10^{c}	10.90±0.11^{c}	70.23±0.45^{c}	19.25±0.12^{b}	9.59±0.24^{d}	16.74±0.14^{b}	18.61±0.17b	28.80±0.28^{c}	21.44±0.19^{c}	21.89±0.32^{ab}
2PPI	135	68.09±0.27^{b}	14.25±0.10^{b}	11.64±0.12^{b}	75.27±0.51^{b}	19.56±0.31^{b}	11.82±0.26^{c}	17.11±0.15^{ab}	19.40±0.30b	30.05±0.33^{b}	22.48±0.23^{b}	22.54±0.74^{ab}
3PPI	139	70.12±0.33^{a}	15.19±0.11^{a}	12.81±0.12^{a}	82.22±0.55^{a}	20.52±0.12^{a}	14.12±0.20^{b}	17.11±0.13^{ab}	20.32±0.23a	31.31±0.28^{a}	22.83±0.19^{b}	25±0.73^{a}
4PPI	121	71.07±0.39^{a}	15.21±0.11^{a}	12.91±0.11^{a}	82.23±0.63^{a}	21.18±0.17^{ab}	15.26±0.35^{a}	17.54±0.17^{a}	20.27±0.17ab	32.05±0.33^{a}	24.19±0.31^{a}	20.71±1.75^{b}
Agro ecology		*	**	**	**	NS	*	*	*	NS	NS	*
Highland	74	68.94±0.38^{a}	15.38±0.17^{a}	12.9±0.17^{a}	81.20±1.00^{a}	20.10±0.15	12.07±0.35^{a}	17.38±0.19^{a}	18.62±0.40^{b}	30.49±0.42	21.77±0.2^{b}	24.29±0.18^{a}
Mid land	141	68.35±0.34^{b}	14.32±0.1^{ab}	12.04±0.11^{b}	76.7±0.57^{b}	19.95±0.14	11.91±0.3^{b}	16.7±0.13^{b}	19.21±0.19^{a}	30.24±0.34	22.8±0.21^{a}	24±0.55^{a}
Low land	335	68.82±0.23^{a}	14.33±0.8^{a}	11.8±0.08^{b}	76.42±0.45^{b}	20.11±0.15	12.9±0.22^{a}	17.22±0.10^{a}	19.98±0.16^{a}	30.55±0.20	22.8±0.16^{a}	21.48±0.4^{b}

1PPI =1 pairs of permanent incisors, 2PPI = 2 pairs of permanent incisors, 3PPI = 3 pairs of permanent incisors and 4PPI = 4pairs of permanent incisors, TC = Thigh circumference, NC = Neck circumference, SC = Scrotum circumference, means within a column with different superscripts are significantly different. * = significant at P≤ 0.05, ** = significant at P<0.01, NS = not significant

Table 5: Correlations between body weight and other linear body measurements of indigenous male and female goats above and below diagonal, respectively

	BWT	BL	WH	STH	CG	CW	CD	RH	RL	RW	PG	HL	HOL	HW	TC	NC	NL	SC
BWT	1	0.8**	0.8**	0.5**	0.9**	0.3**	0.5**	0.8**	0.7**	0.7**	0.8**	0.7**	0.8**	0.4**	0.7**	0.8**	0.6**	0.3*
BL	0.7**	1	0.8**	0.5**	0.9**	0.3**	0.5**	0.8**	0.7**	0.7**	0.8**	0.6**	0.7**	0.4**	0.6**	0.7**	0.5**	0.2ns
WH	0.7**	0.6**	1	0.5**	0.9**	0.4**	0.6**	0.8**	0.7**	0.7**	0.8**	0.6**	0.8**	0.5**	0.7**	0.8**	0.6**	0.4**
STH	0.4**	0.4**	0.6**	1	0.5**	0.5**	0.5**	0.5**	0.6**	0.6**	0.5**	0.3**	0.5**	0.2*	0.4**	0.5**	0.3*	0.3**
CG	0.8**	0.7**	0.7**	0.4**	1	0.5**	0.7**	0.8**	0.8**	0.8**	0.9**	0.7**	0.8**	0.5**	0.7**	0.8**	0.4**	0.4**
CW	0.5**	0.4**	0.4**	0.2**	0.6**	1	0.7**	0.3*	0.4**	0.6**	0.5**	0.2ns	0.3**	0.3**	0.6**	0.3**	0.0ns	0.6**
CD	0.5**	0.4**	0.5**	0.3**	0.6**	0.5**	1	0.4**	0.7**	0.8**	0.5**	0.4**	0.5**	0.2*	0.4**	0.6**	0.0ns	0.6**
RH	0.7**	0.5**	0.7**	0.5**	0.6**	0.3**	0.4**	1	0.7**	0.6**	0.8**	0.7**	0.8**	0.5**	0.6**	0.8**	0.4**	0.2ns
RL	0.7**	0.6**	0.7**	0.5**	0.7**	0.4**	0.6**	0.6**	1	0.8**	0.7**	0.7**	0.7**	0.5**	0.4**	0.8**	0.1ns	0.4**
RW	0.7**	0.6**	0.6**	0.4**	0.7**	0.4**	0.6**	0.6**	0.7**	1	0.7**	0.5**	0.7**	0.5**	0.6**	0.7**	0.3**	0.5**
PG	0.8**	0.6**	0.6**	0.4**	0.8**	0.5**	0.6**	0.7**	0.7**	0.6**	1	0.7**	0.8**	0.6**	0.7**	0.8**	0.4**	0.3**
HL	0.4**	0.3**	0.5**	0.2**	0.4**	0.3**	0.3**	0.5**	0.3**	0.2**	0.4**	1	0.6**	0.7**	0.4**	0.7**	0.3*	0.1ns
HOL	0.6**	0.6**	0.6**	0.3**	0.6**	0.5**	0.4**	0.6**	0.5**	0.5**	0.6**	0.5**	1	0.5**	0.5**	0.8**	0.5**	0.3**
HW	0.4**	0.3**	0.4**	0.2**	0.4**	0.2**	0.2**	0.3**	0.2**	0.4**	0.3**	0.3**	0.3**	1	0.4**	0.6**	0.02ns	0.2ns
TC	0.4**	0.2**	0.3**	0.1*	0.3**	0.1*	0.0ns	0.3**	0.2**	0.0ns	0.2**	0.3**	0.3**	0.3**	1	0.6**	0.3**	0.4**
NC	0.7**	0.6**	0.6**	0.4**	0.7**	0.5**	0.5**	0.6**	0.6**	0.6**	0.6**	0.4**	0.5**	0.3**	0.2**	1	0.4**	0.3**
NL	0.3**	0.3**	0.3**	0.2**	0.3**	0.2**	-0.0ns	0.3**	0.2**	0.1**	0.2**	0.1**	0.2**	0.2**	0.3**	0.1**	1	0.1ns

BW = body weight, BL= body length, WH = withers height, STH = sternum height, CBC = cannon bone circumference, CBL = cannon bone length, CG = chest girth, CW = chest width, CD = chest depth, RH = rump height, RL = rump length, RW = rump width, PG = paunch girth, HL = head length, HOL = horn length, HW = head width, TC = thigh circumference, NC = neck circumference, NL = neck length, SC = scrotum circumference,** significant at (P = 0.01),* significant at (P = 0.05), ns = not significant, na = not available

3.4. Correlation between body weight and linear body measurements

Stepwise multiple linear regression analysis was carried out to generate models (equations) for the prediction of live body weight of male and female goats separately as shown in Table 6. The best-fitted predictors were selected with higher R^2 values by stepwise regression procedure. Chest girth (CG) was the best predictor variable, which explains more variation than any other linear body measurements in both sexes while Body length (BL) and paunch girth (PG) was the second selected predictor variables for males and females, respectively. This result was in line with the report of Alemu (2015), Adem (2018), Getachew (2008), Gebreyesus et al (2012), Hassen *et al*. (2012), Dawit (2012), Seid (2013), Assefa (2013), Tesfahun (2013) and Gatew *et al* (2015) who reported as chest girth was selected first for prediction of live body weight of animals. The predicted equation of body weight for both males and females is presented below.

$$Body\ weight(male) = -42.36 + 1.01\mathrm{CG}$$

$$Body\ weight(female) = -30.13 + 0.83\mathrm{CG}$$

Where CG = Chest girth

Therefore, under field conditions, body weight estimation using chest girth for both male and female goats without a weighting scale would be preferable. Generally, the result of the stepwise regressions procedure was carried out to predict the dependent variable body weight based on independent variables, which had a positive correlation with body weight. The coefficient of determination (R^2) represents the proportion of the total variability explained by the model. Chest girth was more reliable in predicting body weight than other linear body measurements both in male and female goats. This result was in line with the study of Thiruvenkadan (2005) who noted that the better association of body weight with heart girth was possibly due to relatively larger contribution of body weight to heart girth, which consists of bones, muscles, and viscera. Linear body measurements that have higher values to determine the body weights of goats are shown in Table 6.

Table 6: Multiple linear regression analysis of live body weight on different linear body measurements for male and female goats in the study

Models									
Male	I	b1	b2	b3	b4	b5	b6	b7	R^2
CG	-42.36	1.01							0.87
CG+BL	-46.33	0.62	0.54						0.92
CG+BL+NL	-47.88	0.65	0.4	0.33					0.93
CG+BL+NL+SC	-44.52	0.76	0.31	0.35	-0.27				0.94
CG+BL+NL+SC+HL	-46.75	0.68	0.32	0.35	-0.21	0.29			0.95
CG+BL+NL+SC+HL+HW	-44.95	0.71	0.31	0.32	-0.22	0.44	-0.32		0.95
CG+BL+NL+SC+HL+HW+RW.	-41.19	0.66	0.25	0.32	-0.34	0.48	-0.38	0.59	0.95
Female									
CG	-30.13	0.83							0.69
CG+PG	-32.02	0.35	0.49						0.75
CG+PG+RL	-35.14	0.28	0.42	0.93					0.77
CG+PG+RL+TC	-38.46	0.37	0.28	0.99	0.78				0.78
CG+PG+RL+TC+BL	-41.73	0.32	0.26	0.89	0.32	0.16			0.79
CG+PG+RL+TC+BL+HW	-44.16	0.3	0.25	0.92	0.29	0.15	0.3		0.79
CG+PG+RL+TC+BL+HW+STH	-46.23	0.3	0.25	0.79	0.29	0.14	0.29	0.11	0.8

I = intercept, b1, b2… B12 are regression coefficients, CG = chest girth; BL = body length; NL = Neck length, SC = scrotum circumference, HL = head length, HW = head width, RW = rump width, RH = rump height, RL = rump length, PW = paunch girth TC = tie circumference, STH = sternum height, R^2 = R-square

4. Conclusion

This study highlights the significant influence of sex, age, and agro-ecological conditions on the body weight and linear body measurements of goats. Highland, older and female goats outperformed in most of the quantitative traits. The strong positive correlation between body weight and linear body measurements suggests that chest girth combined with body length for males and chest girth combined with paunch girth for females are reliable predictors of body weight. This research serves as a foundational resource for future studies, emphasizing the need for molecular research to further identify and characterize the indigenous goat populations in the region.

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Data availability statement

Data will be made available from the first author upon reasonable request.

Conflicts of interest

The authors declared that there is no conflict of interest.

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