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# On-farm Phenotypic Characterization of Indigenous Goat Types in Selected Districts of South Gondar Zone, North Western Ethiopia

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**Abstract**: This study aimed to gather basic information on phenotypic characteristics and develop live weight estimation equations based on body measurements of indigenous goat types in selected districts of the South Gondar Zone. Multistage purposive sampling was employed based on the potential of goat production. For generating quantitative and qualitative data, linear body measurements were taken from 630 mature goats. Dentition was used to estimate the age of goats as age group one (1PPI), age group two (2PPI), and age group three (3PPI). Data were gathered through field observations and linear body measurements of sampled populations. The most frequently observed coat colors were white (23.80%), white and red (18.57%), red (13.70%), gray (13.17%), brown (9.50%), and black (6.03%). Moreover, the most frequently observed coat color patterns of the sampled goat population in the study area were plain (65.1%), followed by patchy (25.2%) and spotted (9.7%). Sex of animals affected ($P<0.05$) body weight and all of the body measurements except for ear length and tail length. The animals' location difference affected all body measurements ($P < 0.05$), except for heart girth. The age of animals contributed significantly to differences in body weight and all linear body measurements. The correlation coefficient was consistently highest between body weight and chest girth in males ($r = 0.90$) and females ($r = 0.83$). Multiple regression analysis revealed that Chest girth was the most crucial trait in predicting body weight. There was no standard weighing balance for selling live animals at reasonable prices.
**Keywords:** Linear Body Measurements; Multiple linear regression analysis; Quantitative and qualitative traits.

## 1. Introduction

In Ethiopia, livestock is an essential and integral component of agriculture, the backbone of the economy in terms of its contributions to agricultural value-added and national GDP (ILRI, 2011). Ethiopia is one of Africa's largest countries in terms of livestock populations, comprising 54 million goats, 71 million cattle, 43 million sheep, 13.33 million equines, 7 million bee colonies, and 57 million chickens, excluding nomadic areas, and is genetically diverse. Although Ethiopia has a diverse range of large and small ruminants, their productivity has been constrained by numerous complex challenges. Indigenous goat breeds constitute over 95% and 99.77% of the small ruminant population of Africa and Ethiopia, respectively (CSA, 2022). In Ethiopia, the distribution of goats varies between highland and lowland areas. Approximately half of the goat population is kept by pastoralists in the lowlands, while the remaining half is found in small flocks on mixed highland farms. This distribution highlights the significant role goats play in pastoral and mixed farming systems across the country. Goats have a short reproductive cycle and a high multiplication rate compared to large ruminants.

Having developed certain valuable genetic traits, such as the ability to perform better under low conditions and climatic stress, tolerance to infectious diseases and parasites, as well as heat stress, these peculiar traits enable goats to cope with the stressful nature of the vast marginal lands in the region. Goats also have socio-cultural roles in traditional societies. They have often been referred to as the 'poor man's cow' and serve as an essential source of savings for the agrarian community, particularly in developing countries (Seyed et al., 2014). Understanding the existing diversity of management strategies among small-scale keepers (housing, watering, feeding, and health control) and their associated challenges would help develop effective intervention strategies. Characterizing a local genetic resource based on morphological traits plays a crucial role in the classification of animals, particularly in terms of size and shape, which can serve as a reasonable economic indicator (Okpeku et al., 2011). The goat population of Ethiopia has been phenotypically classified into 11 distinct kinds or major breed types, as well as five additional subtypes. However, genetic and molecular characterization revealed only eight distinct breed types or populations in the country. It's well understood that morphological measurements are a critical method used to evaluate and assess the characteristics of various animal breeds. These measurements can help to provide basic information on the suitability of the animals for their selection (Yakubu, 2010). Although phenotypic characterization is vital for breed identification and classification, it is relatively shallow in the South Gondar Zone. Moreover, previous works done by some scholars (Birara et al., 2021; Belete et al., 2022) are not detailed enough to fully explain the potential and physical characteristics of the breed in the zone.

Furthermore, it was area-specific in its coverage and expression of the potential of these animals. In addition to these facts, breed characterization is a prerequisite for animal conservation, documentation, and proper utilization (FAO, 2012; Gizaw et al., 2011). Moreover, the study area has a diversified goat population, but phenotypic characterization has not been conducted so far, particularly for indigenous goat breed types. Thus, this study aimed to phenotypically characterize indigenous goat types in some selected districts of the South Gondar Zone.

## 2. Materials and Methods

### 2.1. Description of the study area

The study was conducted in three districts of the South Gondar Zone, Amhara National Regional State, Ethiopia.

#### 2.1.1. Tach Gayint

It is located in the northeast of Bahir Dar town at a distance of 200 km. The district is bounded by the Lay Gayint district to the north, Simada to the west, the Checheho River to the east, and the Bashilo River to the south (SGADO, 2024). According to SGADO (2024), the district is characterized agro-ecologically as moist *Woina Dega,* with an annual rainfall range of 900 to 1000 mm and a temperature range of 13 to 27 °C. Topographically, the flat area accounts for 24%, the mountainous and hilly areas for 63%, and the valley bottom area for 13%. It lies between 11°21′ and 11°05′ north latitude and 28° 20′ and 28° 42′ east longitude and at an altitude of 750-2800 meters above sea level (masl). The livestock population in the district is estimated to be 28,429 cattle, 73,658 sheep, 81,962 goats, 18,285 equines, 1,305 beehives, and 123,452 poultry (SGADO, 2024).

#### 2.1.2. Simada

It is located at 11°30′ N latitude and 38°15′ E longitude. The district is bordered by the Bashilo River in the southeast, the Abay River in the southwest, the East Estie district in the west, the Lay Gayint in the north, and the Tach Gayint in the northeast. The district is classified as one of the food-insecure areas within the zone due to recurrent climatic and agricultural challenges (MoA, 2023). The total area of the district is approximately 2,244.96 square kilometers, comprising 10% highland, 30% midland, and 60% lowland areas. Elevation ranges from 750 to 3,500 meters above sea level, with an annual temperature range of 15 to 25 °C and an average annual rainfall between 700 and 1,000 mm (NMA, 2023). The soil composition consists of 55% brown, 20% reddish, and 25% black soils, supporting a diverse range of agricultural activities (Abebe et al., 2024). The predominant land use pattern indicates that 145,251 hectares are allocated for cultivation, 12,680 hectares are covered by forest, and 48,291 hectares are used for grazing (SGADO, 2024). The main crops grown include teff, millet, maize, wheat, barley, potatoes, beans, chickpeas, linseed, sorghum, apples, garlic, onions, and haricot beans. Livestock resources are substantial, with populations comprising 58,647 cattle, 92,841 sheep, 96,521 goats, 23,524 equines, 192,658 poultry, and 961 beehives (SGADO, 2024; CSA, 2024).

#### 2.1.3. East Estie

It is one of the districts in the Amhara National Regional State of Ethiopia. Part of the south Gondar zone. It is bordered on the south by the Abay River, on the west by the Estie and Dera districts, on the northwest by the Fogera district, on the east by the Simada district, on the northeast by Lay Gayint, and on the north by the Farta district. The administrative center is Mekane Eyesuse (SGADO, 2024).

### 2.2. Sampling techniques

A multistage purposive sampling technique was employed to capture the diversity and potential of goat production across the South Gondar Zone. Initially, 16 districts within the zone were assessed based on their ecological suitability, existing goat population, and the relative importance of goat production in local livelihoods. From these three districts, Tach Gayint, Simada, and East Estie, were purposively selected due to their high goat production potential and representation of varied agro-ecological zones. Following district selection, a total of 630 indigenous goats were randomly sampled from selected households to obtain data on both linear body measurements and qualitative physical characteristics. This sampling approach ensured representative coverage of phenotypic traits across the study areas (Tsegaye et al., 2024).

### 2.3. Methods of data collection

The goats were classified into three age groups based on their dentition, using the following criteria: 1 PPI (one pair of permanent incisors), 2 PPI (two pairs of permanent incisors), and 3 PPI (three pairs of permanent incisors) to represent ages of less than 2 years, 2–3 years, and more than 3 years, respectively (Wilson and Durkin, 1984; Tesfaye et al., 2021). Moreover, morphological characters (qualitative) and body measurements (quantitative) were collected, and data were recorded in the prepared format. Morphological characters, including coat color pattern, coat color type (CCT), head profile (HP), ears, wattles, horns, ruff, and tail, were observed and recorded using standard color charts (FAO, 2012). Furthermore, quantitative traits including chest girth (CG), body length (BL), wither height (WH), ear length (EL), horn length (HL), rump length (RL), scrotal circumference (SC), and tail length (TL) were measured using a plastic measuring tape. Body weight (BW) was recorded using a spring balance with a 50 kg capacity and 0.2 kg precision (Yimer et al., 2023; Hagos et al., 2022).

### 2.4. Data management and analysis

Morphological and quantitative Data collected from each site were carefully coded and entered into a Microsoft Excel sheet for further analysis. Preliminary data analysis, including homogeneity testing, normality assessment, and outlier screening, was conducted before the primary data analysis for male and female goats within breed and location using the frequency procedure in the Statistical Analysis System (SAS, version 9.1.3). Quantitative character (body weight and linear body measurements) was analyzed using the GLM procedures of SAS Software.

The model used to analyze adult body weight and other linear body measurements was:

$$Y_{ijk} = \mu + D_i + S_j + A_k + (SA)_{jk} + e_{ijk}$$

Where:

$Y_{ijk}$ = the observed body weight and linear body measurements.

$\mu$ = overall mean.

$D_i$ = is the effect of the ith district (Tach Gayint, Simada, and East Estie).

$S_j$ = is the effect jth of sex (female and male).

$A_k$ = is the effect kth of age group (1PPI, 2PPI, and 3PPI).

$S_{jk}$ = is the interaction effect jkth of sex and age.

$e_{ijk}$ = is the random residual error.

Moreover, Pearson's correlation coefficients were used to measure the strength of the relationship between BW and other linear body measurements (LBM) within the same sex and age group. Body weight and other LBM: CG, BL, WH, EL, HL, TL, RL, and SC were included for males but excluded for female goats. Furthermore, the regression procedures in SAS (2008) were used to determine the best-fit regression equation for predicting BW from other LBMs. Thus, the following multiple linear regression models were used to regress BW from different LBM.

**For males**

$$Y_i = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + e_j$$

Where:

$Y_i$ = the response variable; body weight.

$\alpha$ = the intercept.

$x_1, x_2, x_3, x_4, x_5, x_6, x_7$ *and* $x_8$ are the explanatory variables BW, WH, CG, TL, SC, EL, RL, and HL.

$\beta_1 1, \beta_2, \dots, \beta_8$ is the regression coefficient of the variables $x_1, x_2, \dots, x_8$.

$e_j$ = the residual random error.

**For females**

$$Y_i = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + e_j$$

Where:

$Y_i$ = the dependent variable, body weight.

$\alpha$ = the intercept.

$x_1, x_2, x_3, x_4, x_5, x_6$ *and* $x_7$ are the explanatory variables BW, WH, CG, TL, SC, EL, RL, and HL.

$\beta_1 1, \beta_2, \dots, \beta_8$ is the regression coefficient of the variables $x_1, x_2, \dots, x_7$.

$e_j$ = the residual random error.

## 3. Results and Discussion

### 3.1. Qualitative physical characteristics

The coat color pattern among the studied indigenous goat population was predominantly plain (65.1%), followed by patchy (25.23%) and spotted (9.7%) (Table 1). In contrast, Halima et al. (2012) documented a higher frequency of spotted coat patterns (36.1%) in six Ethiopian goat populations, followed by patchy (32.4%) and plain (30.4%) patterns, indicating regional variation in phenotypic traits. In the present study, the most common primary coat color was white (23.8%), followed by white and red (18.57%), red (13.7%), and gray (13.17%). However, a higher prevalence of white coat color (42.5%) was reported in goats from the Babile district in the Oromia region (Mahilet, 2012). Regarding hair type, the dominant coat was short and smooth (79.2%), with a smaller proportion of goats exhibiting long and coarse hair (18.25%). Only 2.54% of the population had a short and coarse hair type. Most goats had straight horns (55.6%), while curved horns accounted for 36.5%. Horn orientation was predominantly backward (59.7%), with the remaining 40.3% showing oblique upward orientation. Ear orientation was pendulous primarily (63.0%), followed by semi-pendulous (28.3%) and erect (8.7%). The head profile distribution showed a high prevalence of concave profiles (73.7%), with smaller proportions exhibiting slightly concave (16.2%) and straight (10.2%) profiles. These variations in morphological traits may stem from unregulated mating practices and gene flow between populations resulting from market-mediated animal movement. Comparable results were reported by Guang-Xin et al. (2018) in Chinese goats, where human-mediated exchanges drove gene admixture. Al-Araimi et al. (2019) also found evidence of population admixture in Omani goats from neighboring regions, underscoring the influence of proximity and movement on genetic and phenotypic diversity. Recent studies by Getachew et al. (2022) and Tadesse et al. (2023) have further confirmed the influence of local ecological and socio-economic factors on the phenotypic variability of indigenous goats in Ethiopia, emphasizing the need for site-specific characterization to facilitate effective conservation and breeding interventions.

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| Character | Tach Gayint | | Simada | | East Estie | | Overall | |
|---|---|---|---|---|---|---|---|---|
| | N | % | N | % | N | % | N | % |
| Body hair coat color pattern | | | | | | | | |
| Plain | 140 | 72.2 | 138 | 62.72 | 132 | 61.68 | 410 | 65.1 |
| patchy (pied) | 44 | 22.7 | 60 | 27.27 | 55 | 24.77 | 159 | 25.23 |
| Spotted | 10 | 5.2 | 22 | 10 | 29 | 13.55 | 61 | 9.7 |
| $X^2$ value | | | | | | | | 50.8* |
| Body hair coat color type | | | | | | | | |
| White | 68 | 35.1 | 37 | 16.8 | 45 | 21.03 | 150 | 23.80 |
| Red | 34 | 17.53 | 41 | 18.6 | 11 | 5.14 | 86 | 13.7 |
| Black | 6 | 3.1 | 4 | 1.82 | 28 | 13.08 | 38 | 6.03 |
| Brown | 15 | 7.7 | 40 | 18.18 | 5 | 2.34 | 60 | 9.5 |
| Gray | 20 | 10.3 | 19 | 8.64 | 44 | 20.56 | 83 | 13.17 |
| White and red | 30 | 15.5 | 38 | 17.27 | 49 | 22.9 | 117 | 18.57 |
| White and black | | | | | 5 | 1.4 | 5 | 1.3 |
| White and brown | | | 7 | 3.18 | | | 7 | 1.11 |
| White and gray | 10 | 5.2 | 16 | 7.27 | 6 | 28 | 32 | 5.1 |
| All color dominant | 11 | 5.7 | 18 | 8.18 | 23 | 10.65 | 52 | 8.3 |
| $X^2$ value | | | | | | | | 101.63* |
| Hair coat type | | | | | | | | |
| Short and smooth | 135 | 69.6 | 163 | 74.1 | 201 | 93.1 | 499 | 79.20 |
| Long and course | 45 | 23.2 | 57 | 25.91 | 13 | 6.01 | 115 | 18.25 |
| Short and course | 14 | 7.2 | | | 2 | 0.9 | 16 | 2.54 |
| $X^2$ value | | | | | | | | 63.03* |
| Horn shape | | | | | | | | |
| Straight | 89 | 45.88 | 141 | 64.1 | 120 | 55.56 | 350 | 55.6 |
| Curved | 76 | 39.18 | 62 | 28.18 | 92 | 45.59 | 230 | 36.5 |
| $X^2$ value | | | | | | | | 31.54* |
| Horn orientation | | | | | | | | |
| Obliquely upward | 82 | 42.27 | 91 | 41.4 | 81 | 37.5 | 254 | 40.3 |
| Backward | 112 | 57.73 | 129 | 58.6 | 135 | 62.5 | 376 | 59.7 |
| $X^2$ value | | | | | | | | 0.97ns |
| Ear orientation | | | | | | | | |
| Erect | 5 | 2.58 | 14 | 6.36 | 36 | 16.67 | 55 | 8.7 |
| Pendulous | 148 | 76.29 | 167 | 75.91 | 82 | 37.96 | 397 | 63.0 |
| Semi-pendulous | 41 | 21.13 | 39 | 17.73 | 98 | 45.37 | 178 | 28.3 |
| $X^2$ value | | | | | | | | 139.75* |
| Facial (head) profile | | | | | | | | |
| Straight | 21 | 10.82 | 25 | 11.36 | 18 | 8.33 | 64 | 10.2 |
| Concave | 156 | 80.41 | 141 | 64.10 | 167 | 77.31 | 464 | 73.7 |
| Slightly concave | 17 | 8.76 | 54 | 24.55 | 31 | 14.35 | 102 | 16.2 |
| $X^2$ value | | | | | | | | 23.84* |
| Wattles | | | | | | | | |
| Absent | 180 | 92.78 | 212 | 96.36 | 209 | 96.76 | 601 | 95.40 |
| Present | 14 | 7.22 | 8 | 3.64 | 7 | 3.24 | 29 | 4.60 |
| $X^2$ value | | | | | | | | $2.79^{ns}$ |
| Ruff | | | | | | | | |
| Absent | 172 | 88.66 | 183 | 83.18 | 172 | 79.63 | 527 | 83.7 |
| Present | 22 | 11.34 | 37 | 16.82 | 44 | 20.37 | 103 | 16.3 |
| $X^2$ values | | | | | | | | 6.04* |

**Table 1** – Q ualitative traits of goat population in the study areas; *= significant, ns = non-significant.

### 3.2. Multiple Correspondence Analyses

Multiple correspondence analyses were carried out for nine (9) qualitative traits recorded to understand the typical features of each district's indigenous goat types morphologically. Figure 1 shows a bi-dimensional graph representing the associations among the categories of the analyzed qualitative traits. The association is based on points located in approximately the same direction from the origin, in a roughly similar region of space. From the figure, it can be seen that 28.28% of the total variation was explained by the first two dimensions (16.98% by the first and 11.30% by the second dimension). On the identified dimensions, the sample goat population in East Estie district clustered together with plain coat color pattern with white, red, and white red coat color type, medium hair length, presence of horn and straight horn shape, semi pendulous and pendulous ear orientation backward and obliquely horn orientation, absence of wattles, flat and sloping rump profile, and straight back profile. The goat population in the Simada district was also closely associated with plain coat color patterns, including white, black, and fawn coat colors, smooth hair coat types, semi-pendulous and pendulous ear orientations, and concave and straight facial profiles. The multiple correspondence analysis revealed that the goat population found in the Estie, Simada, and Tach Gayint districts shares some similar morphological characteristics along the identified dimensions. This might be due to the geographic proximity of the three districts.

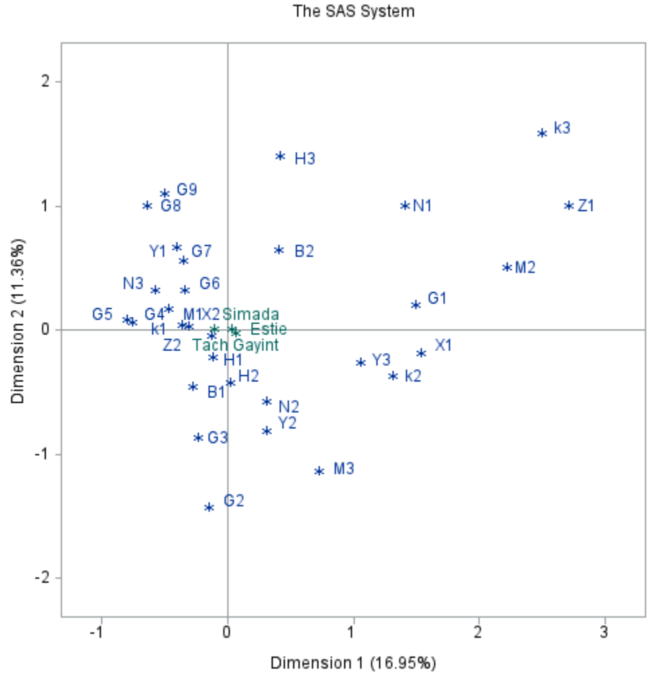


**Figure 1** – A bi-dimensional plot shows the associations among different categories of qualitative variables.

## 3.3. Quantitative physical characteristics

Table 2 shows the BW and LBMs for female and male goats at various ages in different locations.

### 3.3.1. Sex effect

In all three study districts, sex had a statistically significant effect ($P < 0.05$) on most of the measured linear body traits, including BW, BL, CG, HW, HL, and RL. However, EL and TL did not show significant differences between sexes. Across all traits with substantial differences, male goats consistently exhibited higher mean values than their female counterparts. The observed higher values of quantitative traits in male goats can primarily be attributed to physiological and endocrinological differences between the sexes. Notably, the influence of anabolic hormones, such as testosterone, in males enhances muscle growth and skeletal development, contributing to superior growth performance and a larger body conformation compared to females (Gichohi-Wainaina et al., 2023). Moreover, males are less burdened by reproductive physiological demands, which may allow more resources to be directed toward somatic growth (Tesfaye et al., 2021). These findings align with several other studies that have reported sex-related differences in phenotypic traits of indigenous goat populations across diverse agro-ecological zones in Ethiopia and other parts of sub-Saharan Africa (Duguma et al., 2022; Hassen et al., 2020). Understanding such differences is important for designing targeted breeding programs and improving productivity in indigenous goat populations.

### 3.3.2. Age effect

In the sample goat population, age was strongly influenced ($p<0.01$) by all measurements except TL and EL. Body weight, BL, CG, and WH in all age groups were significantly higher ($p<0.01$) in age group 3PPI than in 1PPI and 2PPI. There was wide variability in these body measurements as the age of the animals increased. This implies that these variables best explain the growth pattern of the animals. On the contrary, variables such as ear length and tail length were less influenced by age and showed less variation as age advanced. Similarly, Belete et al. (2022) also reported higher BW, BL, CG, and WH than all age groups in the Lay Gaint and Simada districts of South Gonder zone goat populations. The higher LBMs observed at the maturity stage may be due to muscle development. Moreover, Birara et al. (2021) also reported higher LBMs in both sexes for goat populations in the Farta, Fogera, and Libokemkem districts of the South Gondar zone.

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### 3.3.3. Location effect

Location had a statistically significant influence on BW, BL, HW, HL, SC, and RL, while CG, EL, and TL remained unaffected. The observed spatial differences in linear body measurements (LBMs) could be attributed to disparities in the availability and quality of feed resources across the study sites. In addition, household-level differences in animal husbandry practices, such as housing, healthcare, and feeding regimes, may have contributed to the variability in these traits among the sampled sheep populations. These findings align with recent studies emphasizing the role of environmental and management conditions in shaping phenotypic variation in small ruminants (Gebremedhin et al., 2023; Tsegaye et al., 2022).

### 3.3.4. Sex-by-age interaction effect

The interaction of sex and age group was significant (p<0.01) for CG, BL, BW, HW, and RL, except for EL and TL. In each age group, males had higher values in BW, BL, HW, and HL. The variation in these LBMs between sex and age may be due to variations in measurements at an advanced stage of the animals.

| | CG LSM±SE | WH LSM±SE | BL LSM±SE | BW LSM±SE | EL LSM±SE | TL LSM±SE | HL LSM±SE | SC LSM±SE | RL LSM±SE |
|---|---|---|---|---|---|---|---|---|---|
| Overall | 63.73±0.22 | 60.09±0.02 | 55.22±0.21 | 29.34±0.28 | 20.36±0.09 | 12.12±0.07 | 16.82±0.07 | 5.6±0.8 | 12.23±0.06 |
| $R^2$ | 0.48 | 0.36 | 0.41 | 0.49 | 0.05 | 0.08 | 0.29 | 0.54 | 0.44 |
| CV% | 4.73 | 5.39 | 5.79 | 13.06 | 9.13 | 12.32 | 6.86 | 20.83 | 9.19 |
| **Age group** | * | * | * | * | NS | NS | * | * | * |
| 1 PPI | 58.05±0.46$^{c}$ | 55.59±0.49$^{c}$ | 49.64±0.48$^{c}$ | 22.18±0.58$^{c}$ | 19.48±0.28$^{c}$ | 11.96±0.22$^{b}$ | 15.2±0.17$^{c}$ | NA | 12.30±0.09$^{bc}$ |
| 2PPI | 63.22±0.45$^{b}$ | 59.49±0.48$^{b}$ | 55.08±0.47$^{b}$ | 28.87±0.57$^{b}$ | 20.27±0.28$^{b}$ | 11.89±0.22$^{bc}$ | 16.97±0.17$^{b}$ | NA | 12.62±0.09$^{b}$ |
| 3PPI | 67.38±0.39$^{a}$ | 63.45±0.41$^{a}$ | 58.33±0.41$^{a}$ | 34.72±0.49$^{a}$ | 21.14±0.23$^{a}$ | 12.64±0.19$^{a}$ | 17.76±0.15$^{a}$ | NA | 13.58±0.15$^{a}$ |
| **Age by Sex** | ** | ** | ** | ** | NS | NS | * | Ns | * |
| 1PPI female | 56.59±0.42$^{d}$ | 53.98±0.45$^{d}$ | 47.94±0.45$^{f}$ | 20.23±0.53$^{e}$ | 19.33±0.26$^{c}$ | 10.98±0.21$^{c}$ | 14.83±0.16$^{e}$ | NA | 11.77±0.1$^{c}$ |
| 2PPI female | 60.81±0.36$^{c}$ | 58.2±0.39$^{c}$ | 52.92±0.39$^{d}$ | 25.81±0.47$^{d}$ | 19.94±0.22$^{bc}$ | 12.07±0.18$^{b}$ | 16.19±0.14$^{c}$ | NA | 12.56±0.1$^{bc}$ |
| 3PPI female | 64.07±0.30$^{b}$ | 60.49±0.32$^{b}$ | 55.64±0.32$^{c}$ | 29.77±0.38$^{c}$ | 20.56±0.18$^{b}$ | 12.04±0.15$^{b}$ | 16.72±0.11$^{b}$ | NA | 12.92±0.11$^{b}$ |
| 1PPI male | 59.51±0.79$^{c}$ | 57.19±0.85$^{c}$ | 51.33±0.84$^{e}$ | 24.13±1.01$^{d}$ | 19.63±0.48$^{c}$ | 12.94±0.39$^{a}$ | 15.56±0.3$^{d}$ | 27.5±7.8 | 12.83±0.15$^{b}$ |
| 2PPI male | 65.63±0.80$^{b}$ | 60.77±0.86$^{b}$ | 57.22±0.85$^{b}$ | 31.93±1.03$^{b}$ | 20.61±0.49$^{b}$ | 11.71±0.4$^{b}$ | 17.74±0.3$^{a}$ | 28.7±5.9 | 12.68±0.16$^{bc}$ |
| 3PPI male | 70.70±0.70$^{a}$ | 66.43±0.75$^{a}$ | 61.03±0.74$^{a}$ | 39.67±0.89$^{a}$ | 21.73±0.43$^{a}$ | 13.25±0.34$^{a}$ | 18.8±0.27$^{a}$ | 26.9±6.6 | 14.24±0.28$^{a}$ |
| **Location** | Ns | * | * | * | NS | NS | * | * | * |
| Tach Gayint | 64.5±0.72$^{a}$ | 60.86±0.24$^{a}$ | 54.99±0.24$^{b}$ | 36.73±0.46$^{a}$ | 20.39±0.14 | 12.18±0.11 | 17.3±0.09$^{a}$ | 24.7±0.7$^{b}$ | 13.19±0.09$^{a}$ |
| Simada | 65.01±0.36$^{a}$ | 61.44±0.39$^{a}$ | 55.91±0.38$^{a}$ | 36.29±0.29$^{a}$ | 20.46±0.22 | 12.44±0.17 | 16.8±0.14$^{b}$ | 25.2±0.5$^{b}$ | 12.36±0.08$^{b}$ |
| East Estie | 63.93±0.79$^{a}$ | 60.15±0.31$^{b}$ | 54.95±0.31$^{b}$ | 31.27±0.37$^{b}$ | 19.42±0.18 | 11.31±0.14 | 16.05±0.11$^{c}$ | 26.9±1$^{a}$ | 11.60±0.9$^{c}$ |
| **Sex** | * | * | * | * | Ns | Ns | * | * | * |
| Male | 67.81±0.41$^{a}$ | 63.59±0.45$^{a}$ | 58.42±0.44$^{a}$ | 35.45±0.53$^{a}$ | 20.73±0.25$^{a}$ | 12.69±0.2$^{a}$ | 17.9±0.16$^{a}$ | 28.07±0.67 | 12.06±0.06$^{b}$ |
| Female | 62.06±0.2$^{b}$ | 58.71±0.21$^{b}$ | 53.47±0.21$^{b}$ | 27.09±0.25$^{b}$ | 20.13±0.12$^{a}$ | 11.93±0.09$^{a}$ | 16.2±0.07$^{b}$ | NA | 12.71±0.1$^{a}$ |

**Table 2** – Least square mean (±SE) for body weight and linear body measurements; $^{a,b,\ c,d,e,f,}$ means on the same column with different superscripts within the specified class variable, are significantly different (p<0.05) NA = not applicable *=significant P< 0.05; **= significant (p<0.01), ns= non-significant, BW= body weight, CG=heart Girth, BL= body length, HW= Height at wither, TL=tail length, HL= Horn length, EL=ear length, SC =scrotum circumference, RL = Rump length, SE=standard error.

## 3.4. Correlation between body weight and linear body measurements

The Pearson's correlation coefficients among the quantitative body measurements of indigenous goats, categorized by sex, are presented in Table 3. The results demonstrated that body weight (BW) was significantly and positively correlated with almost all continuous traits assessed in both male and female goats, except for tail length (TL), which showed a weak and inconsistent association. In male goats, BW exhibited strong correlations with heart girth (HG), body length (BL), height at withers (HW), head length (HL), and rump length (RL), with coefficients of 0.90, 0.86, 0.84, 0.69, and 0.55, respectively. Similarly, in females, BW was also strongly correlated with HG (0.83), BL (0.79), HW (0.77), HL (0.50), and RL (0.46). Among these, heart girth consistently showed the highest correlation with BW in both sexes, followed by BL and HW. This strong association between BW and HG suggests that HG can serve as a reliable proxy trait for estimating live body weight in indigenous goats, especially under field conditions where weighing scales are not readily available.

The high correlation between BW and other linear body measurements (LBMs) such as BL, HW, and HL further reinforces the value of morphometric traits in evaluating the growth and productivity of indigenous goats. These findings align with recent studies that emphasized the predictive power of morphometric measurements in estimating BW in local goat populations across various agro-ecological zones. For instance, Tesfaye et al. (2023) reported similar high correlations between BW and HG, BL, and HW in Ethiopian indigenous goats. Likewise, Alade and Onakpa (2022) demonstrated the utility of HG and BL as effective predictors of BW in West African Dwarf goats. A more recent study by Abegaz et al. (2024) validated these associations in highland goat populations, emphasizing the practical application of LBMs in breed characterization and management interventions.

Overall, the results of this study highlight the importance of simple, non-invasive measurements such as HG, BL, and HW in predicting live BW. This is especially useful for smallholder farmers and extension agents in rural areas, enabling better decision-making in selection, nutrition, and health management practices without the need for expensive equipment.

| | BW | HG | BL | HW | HL | TL | EL | RL | SC |
|---|---|---|---|---|---|---|---|---|---|
| **BW** | | 0.83* | 0.79* | 0.77* | 0.50* | 0.24$^{NS}$ | 0.28* | 0.46* | NA |
| **HG** | 0.90* | | 0.69* | 0.74* | 0.49* | 0.22$^{NS}$ | 0.22* | 0.44* | NA |
| **BL** | 0.86* | 0.82* | | 0.75* | 0.49* | 0.21$^{NS}$ | 0.24* | 0.51* | NA |
| **HW** | 0.84* | 0.85* | 0.84* | | 0.45* | 0.22$^{NS}$ | 0.30* | 0.31* | NA |
| **HL** | 0.69* | 0.70* | 0.72* | 0.42* | | 0.25$^{NS}$ | 0.25* | 0.52* | NA |
| **TL** | 0.17** | 0.21** | 0.25* | 0.16** | 0.32* | | 0.12* | 0.19* | NA |
| **EL** | 0.32* | 0.33* | 0.26* | 0.26* | 0.28* | 0.21$^{NS}$ | | 0.19* | NA |
| **RL** | 0.55* | 0.59* | 0.46* | 0.35* | 0.56* | 0.40$^{NS}$ | 0.26* | | NA |
| **SC** | -0.25** | 0.12* | 0.126* | 0.12* | 0.01* | 0.33$^{NS}$ | -0.02* | 0.35* | |

**Table 3** – The correlation coefficient among body weight and linear body measurements (values above the diagonal were for females while below the diagonal were for males): LBM= linear body measurements, HG =heart girth, BL = body length, height at wither, HL = head length, BW =body weight TL= tail length, EL= ear length, SC= scrotum circumference, RL = rump length, **= significant (p<0.01), *=significant (p<0.05). NA = not applicable, NS = non-significant.

### 3.5. Prediction of live body weight from linear body measurements

Multiple regression equations were developed for male (Table 4) and female (Table 5) goat populations to predict BW from LBMs. The LBMs used in the present study were HG, BL, HW, HL, TL, RL, and EL. For optimum model selection, prescreening is advisable to remove the least contributing model terms. A multiple regression procedure was carried out within each sex group on independent variables positively correlated with body weight to predict BW from LBMs. The regression equation was developed to estimate body weight using seven linear body measurements (HG, BL, HW, HL, TL, RL, and EL) in female and male goats. Variables that best fitted the model were selected using the C(p) statistic, $R^2$ (adjusted R-square), MSE (mean square of error), Schwarz Bayesian criteria (SBC), and Akaike's information criterion (AIC). One may define the "best model" as that which has a small value of C(p), which is also close to p (the number of parameters in the model, including the intercept), with the "highest adjusted value, "the highest Schwarz Bayesian Criteria (SBC) and the highest Akaike's information criteria (AIC). The small Cp indicates precision and small variance in estimating the population regression coefficients, while the coefficient of determination ($R^2$) represents the proportion of the total variability the model explains. Chest girth was consistently selected as the best-fitting variable among the others. Thus, CG, BL, HW, and EL were chosen for the female goat, while for male goats, CG, BL, and TL were the best-fitted variables for predicting BW. The prediction of BW could be based on a regression equation developed for both males and females, using CG and other variables (CG, BL, and TL for males) and (CG, BL, HW, and EL for females). According to Hlokoe et al. (2022), regression analysis is a crucial tool in livestock research for determining the relationship between the quantitative response variable and explanatory variables, such as BW and LBM.

This mechanism of analysis is more critical in the absence of weighing balances. Thus, the best-predicted equation where there is no weighing balance at farmers' management condition for the estimation of BW from LBMS was BW= -24.88+0.45HG+0.16BL+0.05HW+0.30EL and BW= -11.57+0.35HG+0.19BL+0.13TL for females (Table 4) and males (Table 5) indigenous goat population in south Gonder Zone, respectively. A similar conclusion was drawn in the study by Hlokoe et al. (2022), which indicated that body weight can be accurately predicted by considering multiple biometric traits. Based on this, it is recommended that traits such as heart girth, withers height, sternum height, rump height, head length, ear length, rump width, and body length be incorporated into breeding programs to improve body weight in male Nguni cattle. For female Nguni cattle in India, heart girth, rump height, and wither height should be prioritized as selection criteria for predicting body weight. Moreover, a previous study by Odadi (2018) found that heart girth is the most reliable indicator for estimating the body weight of heifers in Northern Kenya. Similarly, Ashwini et al. (2019) determined that heart girth, withers height, hip height, and head width are crucial factors in determining the body weight of crossbred cattle in India.

| | I | β1 | β2 | β3 | β4 | $R^2$ | A-$R^2$ | CP | AIC | RMSE | SBC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CG | -22.82 | 0.66 | | | | 0.75 | 0.75 | 93.42 | 654.20 | 1.93 | 661.82 |
| CG+BL | -25.17 | 0.51 | 0.20 | | | 0.77 | 0.77 | 5.80 | 574.62 | 1.81 | 609.32 |
| CG+BL+HW | -23.93 | 0.46 | 0.16 | 0.32 | | 0.78 | 0.78 | 43.03 | 610.39 | 1.76 | 588.50 |
| CG+BL+HW+EL | -24.88 | 0.45 | 0.16 | 0.05 | 0.30 | 0.78 | 0.78 | 24.54 | 593.09 | 1.75 | 590.52 |

**Table 4** – Multiple linear regression analysis of body weight from linear body measurements for female goats, CG =heart girth, BL =body length, TL= tail length, EL= ear length.

| | I | $\beta$ 1 | $\beta$ 2 | $\beta$ 3 | $R^2$ | A-$R^2$ | CP | AIC | RSME | SBC |
|---|---|---|---|---|---|---|---|---|---|---|
| CG | -10.14 | 0.48 | | | 0.68 | 0.68 | 15.75 | 147.99 | 2.14 | 152.64 |
| CG+BL | -13.47 | 0.38 | 0.18 | | 0.71 | 0.70 | 5.81 | 138.82 | 2.02 | 145.81 |
| CG+BL+TL | -11.57 | 0.35 | 0.19 | 0.13 | 0.72 | 0.71 | 3.61 | 121.42 | 1.99 | 132.44 |

**Table 5** – Multiple linear regression analysis of body weight from linear body measurements for male goats, CG =heart girth, BL =body length, TL= tail length.

## 4. Conclusion

The coat color pattern among the sampled goat population was plain, followed by patchy and spotted. Moreover, the primary coat color type of the goat population in the study area was predominantly white, followed by a mix of white and red. The multiple correspondence analysis showed that the goat population in the Estie, Simada, and Tach Gayint districts shares similar morphological characteristics. This might be due to the geographic proximity of the three districts. In all three districts, sex affected the BW, BL, CG, HW, HL, and RL, except for EL and TL. Male goats had consistently higher values than females for these quantitative traits. In the sample goat population, age was strongly influenced ($p<0.01$) by all measurements except TL and EL. The location of the animals had a significant effect on BW, BL, HW, HL, SC, and RL, except for CG, EL, and TL. Pearson's correlation coefficient analysis indicated that BW strongly correlated with all continuous traits of female and male goats except for TL. Moreover, multiple regression analysis showed that the best-predicted equation where there is no weighing balance at farmers' management condition for the estimation of BW from LBMS was BW= -24.88+0.45HG+0.16BL+0.05HW+0.30EL and BW= -11.57+0.35HG+0.19BL+0.13TL for females and male indigenous goat populations in the south Gonder Zone, respectively.

**Ethics approval and consent to participate**:All procedures involving animal use and care were closely monitored during the experimental period. The data collection protocols were reviewed and approved by the Research and Ethics Committee of the School of Animal and Range Science, Haramaya University (SARS 101/22, dated September 9, 2022), as they fulfill the required ethical standards stated in ICLAS (2012).

| Variable name | Levels and descriptions | Variable name | Levels and descriptions |
|---|---|---|---|
| Coat Color Type | G1=White | Ear formation | N1=Erect |
| | G2=Red | | N2=Pendulous |
| | G3=Gray | | N3=Semi Pendulous |
| | G4=Black | Wattle | Z1=Present |
| | G5=White and red | | Z2=Absent |
| | G6=White and brown | Ruff | X1=Present |
| | G7=All Color | | X2=Absent |
| | G8=White and gray | Hair type | K1=Short and Smooth |
| | G9=Brown | | K2=Long and Course |
| Coat Color Pattern | H1=Plain | | K3=Short and Course |
| | H2=Spotted | Horn orientation | B1=Backward |
| | H3=Pied | | B2=Obliquely Upward |
| Head Profile | M1=Concave | Horn shape | Y1=Straight |
| | M2=Straight | | Y2=Curved |
| | M3=Slightly Concave | | Y3=Scours |

List of abbreviations

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**Author's contribution:** Habtamu Kegne and Michael Abera contributed to the design of the study, data collection, analysis, and manuscript writing. Moreover, Kefyalew Alemayehu participated in the study design, data analysis, and manuscript review.

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**Data Availability statement:** The data supporting the findings of this study are available upon request.

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