Phenotypic Characterization of Indigenous Goat Population in Selected Districts of South Gondar Zone, Northern Ethiopia

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Abstract: The study was aimed to generate information on the phenotypic characteristics of indigenous goat populations in selected districts of South Gondar. Two districts were selected based on goat population, altitude difference and potential for goat production. Body weight and linear body measurements were taken from 475 goats of both sexes considering different age groups. Dentition was used to estimate the age of the goats. Both qualitative and quantitative data were analyzed using SAS version 9.40. The frequently observed coat color pattern of goats was patchy (45.2%) for highland and plain (50.7%) for lowland and the main dominantly observed coat color type was red for highland (44%) and lowland (38.6%) goats. All the indigenous goats had horns in both agro-ecologies with the dominant shape to be curved for highland (48%) and lowland (52.9%) goats. Regarding horn orientation, the dominant was a backward type for the highland (44.4%), while it was an upward type for the lowland (39.9%) goats. The back profile was dominated by sloped towards rump for both highland (72.6%) and lowland (55.2%) goats. The dominant facial profile for highland was concave (55.9%), while it was straight (44.4%) lowland goats. The presence of a beard was more common among lowland goats, while wattles were more frequently observed among highland goats. Body weight and most linear body measurements were significantly ($p<0.05$) affected by agro-ecology, sex, age, and sex by age interaction. There were strong and positive correlations between body weight and heart girth as well as with body length, height at wither, rump length, rump width, chest width, and rump height for both sexes. Heart girth and body length were the best explanatory variables for estimation of body weight for the goat population in the study areas. Generally, the goat population found in both study areas was significantly different in phenotypic traits. The current information about the physical characteristics of the goats could be enhanced by conducting genetic analyses. This information can then be used as a foundation for developing effective conservation and breeding strategies. To fully reap the benefits of a breeding program, it is important to take a holistic approach that includes improving non-genetic factors as well.

Keywords: *Indigenous goat, On-farm, Phenotypic characterization, Trait*

Introduction

Ethiopia, endowed with different agro-ecological zones and favorable environmental conditions is a home for many livestock species. It is believed to have the largest livestock population in Africa (Solomon *et al*., 2003; Tilahun and Schmidt, 2012; CSA, 2013). According to the livestock survey (CSA, 2021), the number of goats reported in the country is estimated to be about 50.24 million. About 13.70% of the total goat population of Ethiopia is found in the Amhara region (CSA, 2021). According to FAOSTAT (2016), Ethiopia stands third in terms of breed type. Almost all of the goats in Ethiopia are of the indigenous breed type, which accounts for about 99.9% (CSA, 2021). As a result, the indigenous goat types are widely distributed and are found in all administrative regions of the country. According to FARM-Africa (1996), the indigenous goats are classified into thirteen populations (Barka, Nubian, Abergelle, Central Highland, Western Lowland, North-west Highland, Arsi-Bale, Hararghe Highland, Afar, Short-east Somali, Long-eared Somali, Keffa and Woyto-Guji), however Getinet (2016) regrouped the fourteen indigenous goat types into seven goat types.

Farmers/pastoralists kept goats to provide a vast range of products and services for the owners: such as meat, milk, skin, hair, horns, bones, manure, security, gifts, religious rituals, and medicine (Tesfaye, 2009; Grum, 2010; Tadesse *et al*., 2013). They are important protein sources in the diets of the poor and help to provide extra income and support (Nottor, 2012).

The characterization of local genetic resource based on morphological trait plays a very fundamental role in classification of animals based on size and shape in turn which to some extent reasonable economic indicator (Halima *et al*., 2012). Genetic and phenotypic characterizations are the two basic breed classification techniques widely used to describe livestock (FAO, 2007), even though it is criticized by genetic or molecular studies, because of difficulties in validating such results. Identification, characterization, and documentation of goat breeds are important for any type of development or improvement work. Without such documentation, it

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would be difficult to know the animals and their potential (Kassahun and Solomon, 2008).

Amhara Regional State particularly the South Gondar Zone is endowed with a large and diverse goat population and often populations bear the name of communities that own them and or the location in which they are found. However, there is no clear phenotypic or genetic evidence that shows the relation between these names and differential adaptive traits of the distinct breed types in the highland part of Lay-Gayint and the lowland part of Semada districts in South Gondar Zone, except a report by Halima *et al.* (2012), who conducts on-farm characterization in the South Gondar Zone by taking 30 goats as a study population. However, the author did not address the current study districts. Moreover, in the current study districts, there is limited information to utilize the indigenous goat genetic resources and for searching out the adaptation and productive performance of indigenous goat populations. In addition, phenotypic characterization is very important for future molecular characterization, breeding, and conservation activities. Thus, the study aimed to identify the phenotypic and morphological characteristics of the indigenous goat population under farm management in the Lay-Gayint and Semada districts of Amhara Regional State.

Materials and Methods

Description of the Study Areas

The study was conducted in two districts, namely, Semada and Lay-Gayint of South Gondar Zone of Amhara Regional State, Ethiopia. South Gondar Zone is one of fifteen administrative zones in the Region. The zonal capital city is Debre-Tabor and it is located at 11°02'-12°33' N latitude and 37°25'-38°43' E longitudes with 1428.73 sq km. This Zone is bordered in the south by East Gojjam, in the southwest by West Gojjam and Bahir-Dar, in the Lake Tana, in the north by North Gondar, in the north east by Wag Hemra, in east by North Wollo, and in the southeast by South Wollo. The Abbay River separates South Gondar from the two Gojjam zones (South Gondar Administrative Agriculture Office, 2016). The description of the specific study districts is presented in Table 1.

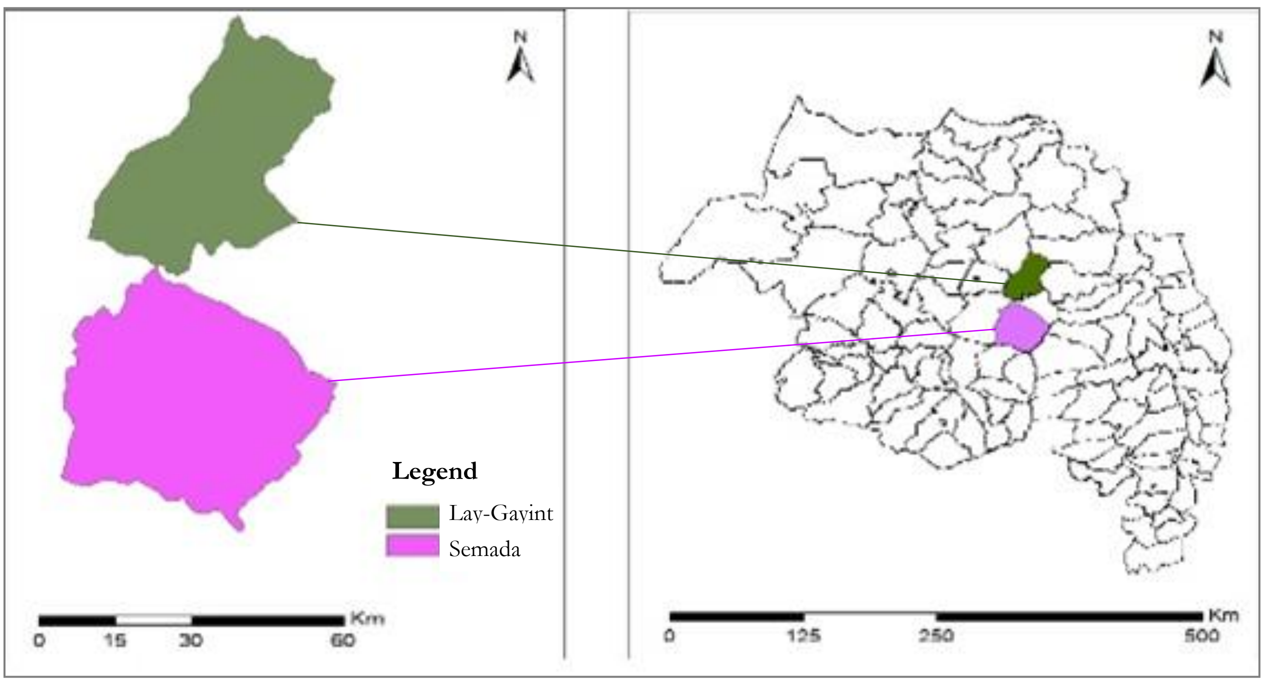

Figure 1. Study area map showing the study districts in Amhara Regional State (Source: Lay-Gayint District Office of Agriculture, 2016; Semada District Office of Agriculture, 2016).

Sampling Method

Purposive sampling was applied to select the study districts, which are Lay-Gayint and Semada based on the availability of large goat populations and accessibility. Similarly, from each sampling district, *kebeles* (the smallest administrative units) were purposively selected based on goat population size and accessibility. A total of 475 (304 female and 171 male) goats from all sampling districts were taken for linear body measurements and qualitative trait study. Sampling was based on the following formula:

$$n= (\frac{Z}{M})^2 p\ (1 - p)\ \text{(Cochran, 1977).}$$

Where, z is the value (e.g. 1.96 for 95 percent confidence level); m is the margin of error (e.g. 0.05 = + or – 5 percent); and *p* is the estimated value for the proportion of the sample that will respond to a given way to a survey question (e.g. 0.50 for 50 percent) (Cochran, 1977). Secondary information on the distribution and number of goats across the different districts was obtained from agricultural and rural development offices of the Zone and respective districts before starting the actual fieldwork. The sample distribution across the districts is presented in Table 2.

Table 1. Description of the study districts.

Description	Lay-Gayint district	Semada district
Location	11°32'-12°16 north latitude and 38°12'-38°19'east longitude	11° 02'-11°39'north latitude and 38°06'-38°38'east longitude
Altitude	1500-4231 m.a.s.l.	2460 m.a.s.l.
Annual rainfall	600-1200 mm	1000-1500 mm
Average temperature	8 to 20 °C	16-23°C
Total area coverage	154856 hectare	951363.9 hectare
Bordered:		
East	Mekiate *woreda*	South Wollo
West	Estie and Farita *woreda*	East Estie
North	Ebinat	Tach-Gayint and Lay-Gayint
South	Tach-Gayint	East Gojjam Zone
Human population:		
Male	102,109	122071
Female	99,678	123686
Total	201,787	245757
Agro-ecology zone:		
Frost	2.71%	0%
Highland	45.39%	11%
Midland	39.4%	41%
Lowland	12.5%	48%
Livestock population:		
Cattle	120579	144349
Sheep	82510	98568
Goat	48758	108898
Horse	4842	353
Donkey	21769	21617
Mule	1249	734
Poultry	60583	86944

Table 2. Summary of sampling.

District	Number of *kebeles*	Goat population			Number of households	Group discussion
		Male goat	Female goat	Total		
Lay-Gayint	4	73	179	253	90	4
Semada	3	98	125	223	90	3

Qualitative and Quantitative Traits

The major physical features/qualitative traits of goats were collected from field observation using the FAO (2012) characterization guide. The most important qualitative traits were coat color, coat color pattern, head profile, horn presence/absence, horn shape, horn orientation, ear orientation, back profile, hair type, wattle presence/absence, and beard presence/absence. Morphometric measurements were made on the quantitative traits of goats using measuring tape. The measurement was made on animals that were classified based on sex and age group. The linear body measurement was made using plastic tape, whereas body weight of animals was measured using a suspended spring or Salter weighing scale having a 50 kg capacity with 0.2 kg precision. The quantitative traits included in the data collection were: live body weight (BW), heart girth, body length, height at wither, rump length, rump width, rump height, ear length, horn length, pelvic width, scrotum circumference, and scrotum length (FAO, 2012).

Data Management and Analysis

All data collected during the study period were coded and recorded in Microsoft Excel 97-2003. Preliminary data analysis like homogeneity test, normality test and screening of outliers were employed before conducting the main data analysis. Qualitative data was analyzed separately for each sex and study district using the frequency procedure (PROC FRQ) of the Statistical Analysis System (SAS version 9.40, 2013), whereas the General Linear Model (PROC GLM) procedure of the same software was employed for analysis of body weight and other liner body measurements' (LBM) data. For adult animals, the sex and age group of the goat and location (districts) were fitted as independent variables while body weight and linear body measurements were fitted as dependent variables. Least square means (LSM) with their corresponding standard errors were estimated for each body trait over sex, age, districts and age-by-sex interaction. When analysis of variance declared significant difference, least square means were separated by using Tukey's HSD test. Only significant interactions among fixed effects were discussed.

The model employs for analyses of body weight and other linear body measurements (LBMs) except scrotal circumference (SC) and scrotal length (SL) were:

$Y_{ijk} = \mu + A_i + S_j + D_k + A_i{*}S_j + e_{ijk}$

Where: Y_{ijk} = the observed (body weight or LBMs) in the i^{th} age group, j^{th} sex and k^{th} district

μ= overall mean,

A_i = the effect of i^{th} age group (i = 0, 1, 2, ≥3) PPI

S_j = the effect of j^{th} sex (j = female or male)

D_k = the effect of K^{th} agro-ecology (K = highland and lowland)

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

e_{ijk} = random residual error

The model used to analyze scrotal circumference (SC) and scrotal length (SL) was:

$Y_{ik} = \mu + A_i + D_k + e_{ijk}$

Where: Yik = the observed l (SC or SL) in the i^{th} age group and k^{th} agro-ecology

μ = overall mean

A_i = the effect of i^{th} age group (i = 0, 1, 2, ≥3) PPI

D_k = the effect of k^{th} agro-ecology (k = highland and lowland)

e_{ijk}= random residual error

Pearson correlation coefficient was estimated between body weight and linear body measurements within sex and age groups. Body weight was regressed on linear body measurements for each sex, for each age class and for pooled by sex using the stepwise regression procedure of SAS (SAS version 9.40, 2013) to select the best-fitted regression equation for prediction of body weight. Stepwise multiple linear regression analysis used to obtain best prediction equations for body weight from body measurement variables (Cam *et al.,* 2010).

The criteria used to select the best-fitted regression equation were coefficient of determination (R^2), the Mallows C parameters C (P), Root Mean square of error (RMSE), and Simplicity of the measurement under the field condition. Separate models were used for male and female goat populations during estimation of body weight from linear body measurements. The small C (p) (the Mallows C parameter), variance (Mean square error) and the coefficient of determination were used to evaluate the efficiency of the model. The small C (p and variance (Mean square error) indicate precision while the coefficient of determination (R^2) represents the proportion of the total variability which is explained by the model.

Multiple linear regression models for females:

$Y_j = \beta_0 + \beta_1X_1 + \beta_2X_2 + \text{----} \beta_4X_4 + e_j$

Where: Y_j = the dependent variable body weight, β_0 = the intercept, X_1, X_2, --- X_4 are the independent variables such as heart girth, body length, rump length, and rump height, respectively; β_1, β_2, --- and β_4... are the regression coefficients of the variables X_1, X_2, --- X_4, respectively; and ej = the residual error.

Multiple linear regression models for males:

$Yj = \beta_0 + \beta_1X_1 + \beta_2X_2 \text{---}+ \beta_4X_4 + e_j$

Where: Y_j = the dependent variable body weight, β_0 = the intercept, X_1, X_2, ---. X_4 are the independent variables such as heart girth, body length, scrotal circumference and scrotal length, respectively; β_1, β_2, --- β_4 are the regression coefficients of the variables X_1, X_2, --- X_4, respectively; and e_j = the residual error.

Results and Discussion

Qualitative Characteristics of the Indigenous Goat Population

The physical characteristics of 171 male and 304 female indigenous goats across the study areas are presented in Tables 3 and 4. The study showed that out of the total sampled population, the major coat color pattern observed in the highland area goat population for both sexes was patchy (45.2%), plain (33.7%) and spotted (21%) with the dominant coat color red (45.2%),white (37.3%), black (7.1%) and brown (4.8%) (Figure 2). In the lowland area goat population, for both sexes, the dominant coat color pattern were plain (50.7%), patchy (36.8%) and spotted (12.6%) with the dominant coat color to be red (38.6%), white (38.6%), black (9.4%) and brown (6.3%) (Figure 3). The dominant coat color pattern, which includes the red coat color, aligns with the current finding for highland goats. This was reported by Farm-Africa (1996), Netsanet (2014), and Bekalu *et al.* (2016) for the Central Highland goat and West Gojjam Zone goat populations, respectively. In contrary to the current study on Begia-Medir and Central Highland goats, Halima *et al.* (2012) and Alubel (2015) described this goat population as white with spotted white coat color type respectively. The hair type of the indigenous goat population in both areas was dominated by short smooth hair type followed by coarse type. This result agreed with the report of FARM-Africa (1996), Kassahun and Solomon (2008), Halima *et al.* (2012), Seifemichael *et al.* (2014), Yaekob *et al.* (2015) and Bekalu *et al.* (2016) for Central Highland goat, Rift Valley family goat type, indigenous goat population of Ethiopia, Afar goat, Woyto-Guji goat and indigenous goat types in West Gojjam Zone, respectively. All (100%) the goats were horned in both areas with a majority of curved horn shapes and frequent orientations to be backward and upward horns. However, this finding proved that between sexes, male goat has long horns compared to female goats.

Ear orientation was dominantly semi-pendulous followed by carried horizontally, pendulous, and erect. However, across the study areas, both the highland and lowland goat dominantly showed semi-pendulous ear orientation. This result is similar to the report of Alubel (2015) and Hussein (2015) for Central Highland and low land of Arsi-Bale goats, respectively. On the contrary, the current findings contradict with the report by Netsanet (2014) for the Central Highland goat. This difference may be attributed to variations in sampling sites and time frames. The facial head profile of indigenous goats in the highland and lowland areas for both sexes dominantly showed concave and straight, respectively. This finding agreed with the result of FARM-Africa (1996), Dereje *et al.* (2013) and Yaekob *et al.* (2015) for Central Highland and Woyto-Guji goats (Rift Valley family), respectively.

The occurrence of wattles in indigenous goats was bilateral and found on both sexes. A higher number observations of wattle was recorded in the highland area than in the lowland area. Beard presence was recorded across the study areas and on both sexes of the indigenous goat population. The lowland goat was characterized by a larger beard compared to the highland goat, and the presence of a beard was more commonly observed in male goats throughout the study area. Similar results were also reported by Grum (2010) for the Short-eared Somali goat type, Dereje *et al.* (2013) for Hararghe Highland goats, Netsanet (2014) for Central Highland goats and Bekalu *et al.* (2016) for West Gojjam Zone goat population. On the other hand, this result disagreed with the report of Hussein (2015) for lowland Aris-Bale goat, Alubel (2015) for Abergelle and Central Highland goats and Bekalu *et al.* (2016) for indigenous goat types in west Gojjam Zone. Based on the chi-square analysis of the considered categorical variables, coat color pattern, coat color type, facial profile, horn shape, horn orientation, ear form, hair type, beard, and back profile were significantly ($p<0.05$) different within the sample goat population. According to Hagan *et al.* (2012), in addition to the thermoregulatory functions, the presence of wattle and beard are associated with reproduction traits such as higher prolificacy, higher milk yield, higher liter size, fertility, and conception rate. The back profile dominantly observed was sloping towards the rump followed by sloping from withers (for highland goats) and straight type (for lowland goats).

Figure 2. Highland area adult female (left) and male (right).

Figure 3. Lowland area adult female (left) and male (right).

Table 3. Phenotypic characteristics of the indigenous goat population in the highland area.

Qualitative trait	Level	Male		Female		Both	
		N	%	N	%	N	%
Coat color	Black	5	6.8	13	7.3	18	7.1
	White	32	43.8	62	34.6	94	37.3
	Read	28	38.4	83	46.4	111	44
	Brown	2	2.7	10	5.6	12	4.8
	Roan	4	5.5	5	2.8	9	3.6
	Gray	1	1.4	2	1.1	3	1.2
	Black and white	1	1.4	4	2.2	5	2
	Chi-square						***
Coat color pattern	Plain	23	31.5	62	34.6	85	33.73
	Patchy	31	42.5	83	46.4	114	45.24
	Spotted	19	26	34	19	53	21.03
	Chi-square						***
Head profile	Straight	16	21.9	67	37.4	83	32.94
	Concave	40	54.8	101	56.4	141	55.95
	Convex	16	21.9	11	6.2	27	10.71
	Ultra convex	1	1.4	0	0	1	0.4
	Chi-square						***
Horn presence	Present	73	100	179	100	252	100
	Absent	0	0	0	0	0	0
	Chi-square						00
Horn shape	Straight	17	23.3	29	16.2	46	18.25
	Curved	48	65.8	73	40.8	121	48.02
	Spiral	8	10.9	67	37.4	75	29.76
	Corkscrew	0	0	10	5.6	10	3.97
	Chi-square						***
Horn orientation	Lateral	2	2.7	9	5	11	4.4
	Upward	18	24.7	91	50.8	109	43.3
	Backward	43	58.9	69	38.6	112	44.4
	Not clear	10	13.7	10	5.6	20	7.9
	Chi-square						***
Ear orientation	Erect	3	4.1	1	0.56	4	1.59
	Pendulous	23	31.5	58	32.4	81	32.14
	Semi-pendulous	38	52.1	90	50.28	128	50.79
	Carried horizontal	9	12.3	30	16.76	39	15.48
	Chi-square						***
Back profile	Straight	5	6.8	25	14	30	11.9
	Slopes towards the rump	54	74	129	72.1	183	72.6
	Slopes down from withers	13	17.8	19	10.6	32	12.7
	Curved(dipped)	1	1.4	6	3.3	7	2.8
	Chi-square						***
Hair type	Short smooth	56	76.7	135	75.4	191	75.8
	Coarse	17	23.3	44	24.6	61	24.2
	Chi-square						***
Wattle	Present	19	26	160	89.4	179	71.03
	Absent	54	74	19	10.6	73	28.97
	Chi-square						***
Beard	Present	46	63	23	12.8	69	27.4
	Absent	27	37	156	87.2	183	72.6
	Chi-square						***

****Indicates significant at p<0.001; 00 Indicates chi-square value zero.*

Table 4. Phenotypic characteristics of indigenous goat population in the lowland area.

Qualitative trait	Level	Male		Female		Both	
		N	%	N	%	N	%
Coat color	Black	8	8.2	13	10.40	21	9.4
	White	49	50.0	30	24	79	35.4
	Read	31	31.6	55	44	86	38.6
	Brown	4	4.1	10	8	14	6.3
	Roan	2	2	11	8.8	13	5.8
	Gray	1	1	3	2.4	4	1.8
	Black and white	3	3.1	3	2.4	6	2.7
	χ2 within district						***
	χ2 between district						***
Coat color pattern	Plain	51	52	62	49.6	113	50.7
	Patchy	36	36.7	46	36.8	82	36.8
	Spotted	11	11.2	17	13.6	28	12.5
	χ2 within district						***
	χ2 between district						***
Head profile	Straight	31	31.6	68	54.4	99	44.4
	Concave	13	13.3	50	40	63	28.2
	Convex	52	53.1	7	5.6	59	26.5
	Ultra convex	2	2	0	0	2	0.9
	χ2 within district						***
	χ2 between district						***
Horn presence	Present	98	100	125	100	223	100
	Absent	0	0	0	0	0	0
	χ2 within district						00
	χ2 between district						00
Horn shape	Straight	36	36.73	37	29.6	62	27.8
	Curved	41	41.84	67	53.6	118	52.9
	Spiral	21	21.43	21	16.8	43	19.3
	Corkscrew	0	0	0	0	0	0
	χ2 within district						***
	χ2 between district						***
Horn orientation	Lateral	3	3.1	5	4	8	3.6
	Upward	37	37.8	52	41.6	89	39.9
	Backward	37	37.8	48	38.4	85	38.1
	Not clear	21	21.4	20	16	41	18.4
	χ2 within district						***
	χ2 between district						***
Ear orientation	Erect	13	13.3	17	13.6	30	13.5
	Pendulous	26	26.5	35	28	61	27.4
	Semi-pendulous	46	46.9	55	44	101	45.3
	Carried horizontal	13	13.3	18	14.4	31	13.9
	χ2 within district						***
	χ2 between district						***
Back profile	Straight	29	29.6	42	33.6	71	31.8
	Slopes towards the rump	58	59.2	65	52	123	55.2
	Slopes down from withers	10	10.2	17	13.6	27	12.1
	Curved(dipped)	1	1	1	0.8	2	0.9
	χ2 within district						***
	χ2 between district						***
Hair type	Short smooth	92	93.9	116	92.8	208	93.3
	Coarse	6	6.1	9	7.2	15	6.7
	χ2 within district						***
	χ2 between district						***
Wattle	Present	3	3.1	9	7.2	12	5.38
	Absent	95	96.9	116	92.8	211	94.62
	χ2 within district						***
	χ2 between district						***
Beard	Present	68	69.4	23	18.4	91	40.8
	Absent	30	30.6	102	81.6	132	59.2
	χ2 within district						**
	χ2 between district						***

*** Indicates significant at P<0.01; *** Indicates significant at p<0.001; 00 Indicates chi-square value zero; χ2 between district means comparison with values mentioned for high land goats in Table 3.*

Quantitative Traits' Characteristics of Indigenous Goat Population

Effect of agro-ecology: Agro-ecology has affected body weight and linear body measurements. In this study, all except rump width showed significant differences between agro-ecology which means agro-ecology has significant effect ($p<0.001$) on body weight and other linear body measurements (Table 5). The values of the highland goat were higher than the lowland goat, except tail length was higher for the lowland goat ($p<0.05$). This may be due to the sample size. This result agreed with the report of Biruh (2013) for Woyto-Guji goats. On the contrary, the current finding disagreed with the report of Tsigabu (2015) for the Nuer Zone goat population. The variation in body weight between goats of different locations could be explained by the different management systems, sampling differences, types of farming systems, and the presence of strains within the breed.

Effect of sex: Except for ear length, sex had a highly significant effect ($p<0.001$) and revealed an important source of variation in body weight and other liner body measurements across the study area (Table 5). Except for body length and pelvic width, the values of male goats were significantly higher than female goats. In this investigation male goats were found significantly ($p<0.001$) heavier than female goats across the study areas. This result is in agreement with the findings of Alubel (2015) and Bekalu *et al.* (2016) for the Central Highland goat breed and indigenous goat population in the west Gojjam Zone, respectively. On the other hand the present finding is in contrast with the report of Alade *et al.* (2008), Sowande *et al.* (2009), Semakula *et al.* (2010) and Okbeku *et al.* (2011), where female goat have higher body weight and other body measurements than male counterpart. The influence of sex on the body weight and all morphometric traits except body length might be the usual difference between sexes due to hormonal actions leading to differential growth rates (Frandson and Elmer, 1981).

Effect of age: Age strongly influenced ($p<0.001$) body weight and body linear measurement for indigenous goats (Table 5). Body weight was strongly significantly ($p<0.001$) affected by age group with a sharp increase from 0PPI to 4PPI. This predicted that the size and shape of goats change as their age increased. This result is similar with the report of Belete (2013), Dereje *et al.* (2013), Grum *et al.* (2014), Solomon (2014) and Hussein (2015). All linear body measurements were also significantly ($p<0.001$) affected by the age of the goat and increased as the age increased from 0PPI to 4PPI. However, there was no significant difference between 3PPI and 4PPI on rump width, tail length, neck length, ear length, rump length, and chest width. This result agreed with the finding of Bekalu *et al.* (2016). Under normal conditions, animal grow fast when younger but grow slowly when they reach at maturity (Yoseph, 2007). Furthermore, the rate of increase in body weight is minimal as the goat advances in age and endorsed the attainment of mature weight at a later age (Dereje *et al.,* 2013).

Effect of sex by age: The interaction between sex and age group significantly ($p<0.001$) affected body weight and LBMs, and except for neck length, chest width, rump length, and ear length all other variables were highly significant ($p<0.001$). Whereas, the effects of age by sex interactions on rump length and chest width were significant. However, neck length was significantly ($p<0.05$) affected by this factor (Table 5). The result revealed that when the age increased the variation also increased and the value of male was higher in all measurement. The higher body weight of males compared to females at all ages can be attributed to the aggressive behavior exhibited by males during feeding and sucking, as well as the presence of male sex hormones that have an anabolic effect. This finding is consistent with the results reported by Grum (2010), Mahilet (2012), and Bekalu *et al.* (2016) for Short-eared Somali goats, Hararghe Highland goats, and the indigenous goat population in the West Gojjam Zone, respectively. Frandson and Elmer (1981) also reported that the observed variation in body weight is due to differential levels and expression of sex hormones, particularly the release of androgen, which is known to stimulate growth and weight gain in male animals after the testes are fully developed.

Correlation Between Body Weight and Linear Body Measurements

The correlation coefficient analyses were carried out to figure out and establish the relationship between live body weights with other body measurement traits for highland and lowland goat populations (Table 6 & 7). Accordingly, correlation coefficients (r) between live weight and other body measurement traits were found positive with the presence of highly significant ($p<0.001$) associations of body weight with heart girth for both highland (male, $r= 0.99$ and female, $r=0.96$) and lowland (male, $r= 0.98$ and female, $r=0.97$) goats. The highest correlation between heart girth and live body weight is in agreement with other findings (Halima *et al.*, 2012; Netsanet, 2014; Alubel, 2015; Hussein, 2015 and Bekalu *et al.*, 2016), which indicates that the body weight of goats can be predicted from heart girth measurements of goats. However, correlation coefficients could be affected by factors like age, sex, season, and feeding conditions. So, it is not expected to achieve the same results in different breeds and environments, and the effectiveness of body measurements in body weight prediction could be changed (Cam *et al.*, 2010). For highland goats, other linear body measurements had a small to high positive correlations (0.09 to 0.95) with one another for both sexes. On the other hand, for lowland goat type, body length, rump height, height at wither, rump width, horn length, pelvic width, chest width, rump length, neck length, tail length, and ear length had a negative to high positive correlation (-0.02 to 0.95) with one another for both sexes except for tail length, which did not correlate with body length, ear length, and with other liner body measurement for lowland goat. This result agrees with the report of Netsanet (2014) and Bekalu *et al.* (2016). The positive correlations between body weight and morphometric traits obtained in the present study indicate that an increase in any one of the body measurements would result in a corresponding increase in live body weight. The strong relationship existing between BW and body measurements suggests that the combination of these morphological traits could be used to estimate live weight in goats fairly well in the situations where weighbridges or scales are not available. The association may also be useful as selection criterion since positive correlations of traits suggest that the traits may be under the same genetic influences (Jimmy *et al*, 2010).

Table 5. Least square mean (± SE) body weight (kg) and other linear body measurements by sex, age, agro-ecology, and sex by age interaction.

Effect-level		N	HG	WH	BL	LBW	PW
			LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE
Over all		475	71.52±0.34	68.77±0.31	64.00±0.30	31.09±0.43	13.76±0.07
R2			0.67	0.61	0.63	0.70	0.48
CV%			6.01	6.27	6.31	16.60	8.28
Sex	M	171	75.73±0.75[a]	73.59±0.71[a]	61.86±0.64[a]	37.42±0.97[a]	13.31±0.16[a]
	F	304	69.25±0.32[b]	66.41±0.28[b]	67.71±0.30[b]	27.92±0.38[a]	14.79±0.07[b]
			****	***	***	***	***
Age	0PPI	96	63.10±0.47[e]	61.94±0.60[e]	57.18±0.50[e]	21.23±0.46[e]	12.34±0.12[e]
	1PPI	63	67.40±0.61[d]	66.79±0.69[d]	60.67±0.65[d]	25.93±0.74[d]	13.11±0.15[d]
	2PPI	97	72.69±0.50[c]	70.17±0.56[c]	65.72±0.55[c]	32.35±0.67[c]	14.09±0.14[c]
	3PPI	116	78.02±0.54[b]	74.34±0.50[b]	69.22±0.56[b]	39.76±0.75[b]	15.03±0.13[b]
	4PPI	103	81.15±0.60[a]	76.74±0.57[a]	71±0.49[a]	44.08±0.84[a]	15.66±0.14[a]
			***	***	***	***	***
Agro-ecology	Highland	252	74.07±0.31[a]	72.30±0.31[a]	66.83±0.29[a]	34.99±0.38[a]	14.14±0.08[a]
	Lowland	223	70.91±0.31[b]	67.69±0.31[b]	62.74±0.29[b]	30.34±0.37[b]	11.78±0.08[b]
			***	***	***	***	***
Sex by Age	F0PP1	23	62.69±0.84[e]	61.20±0.78[e]	56.94±1.11[e]	20.72±0.84[e]	12.13±0.19[g]
	F1PPI	34	64.96±0.57[e]	64.02±0.69[e]	57.70±0.72[e]	22.61±0.63[e]	12.97±0.20[efg]
	F2PPI	70	70.25±0.43[d]	66.99±0.48[d]	62.29±0.47[d]	38.53±0.51[d]	13.41±0.15[de]
	F3PPI	88	73.54±0.49[c]	69.72±0.45[c]	65.74±0.42[bc]	33.12±0.60[c]	13.89±0.09[cd]
	F4PPI	89	74.81±0.47[c]	70.12±0.40[c]	66.62±0.41[b]	34.64±0.55[c]	14.18±0.10[bc]
	M0PP1	73	63.51±0.56[e]	62.69±0.75[e]	57.43±0.56[e]	21.75±0.55[e]	12.56±0.15[fg]
	M1PPI	29	70.00±0.97[d]	69.57±1.11[fc]	63.64±0.92[cd]	29.24±1.20[d]	13.26±0.24[def]
	M2PPI	27	75.13±0.18[c]	73.35±1.26[b]	68.15±0.27[b]	36.16±1.65[c]	14.77±0.26[b]
	M3PPI	28	82.51±0.97[b]	78.96±0.84[a]	73.35±0.86[a]	46.40±1.50[b]	16.17±0.23[a]
	M4PPI	14	87.50±1.18[a]	83.37±1.67[a]	76.03±1.42[a]	53.53±2.63[a]	17.14±0.38[a]
			***	***	***	***	***
Effect-level		N	HL	EL	RH	CW	RL
			LSM±SE	LSM±SE	LSM±SE	LSM±SE	
Over all		475	10.83±0.23	13.89±0.06	72.59±0.29	15.35±0.11	18.17±0.10
R2			0.61	0.22	0.56	0.40	0.43
CV%			29.50	8.57	5.77	12.01	9.51
Sex	M	171	15.44±0.51[a]	13.79±0.11[a]	75.94±0.61[a]	16.89±0.22[a]	19.21±0.21[a]
	F	304	8.67±0.20[b]	14.00±0.07[a]	70.63±0.29[b]	14.51±0.11[b]	17.65±0.11[b]
			***	Ns	***	***	***
Age	0PPI	96	68.32±0.28[e]	13.23±0.12[c]	66.38±0.52[d]	16.15±0.17[c]	14.11±0.19[c]
	1PPI	63	8.83±0.49[d]	13.69±0.15[bc]	69.90±0.66[c]	17.66±0.26[c]	15.32±0.27[b]
	2PPI	97	12.74±0.44[c]	13.91±0.13[ab]	73.93±0.54[b]	18.42±0.24[b]	17.04±0.18[b]
	3PPI	116	15.52±0.48[b]	14.27±0.12[a]	77.85±0.44[a]	19.69±0.22[a]	18.66±0.18[a]
	4PPI	103	17.14±0.50[a]	14.39±0.12[a]	78.36±0.51[a]	20.24±0.20[a]	19.54±0.21[a]
			***	***	***	***	***
Agro-ecology	Highland	252	12.33±0.23[a]	14.24±0.09[a]	75.42±0.31[a]	15.87±0.13[a]	19.21±0.13[a]
	Lowland	223	11.78±0.23[a]	13.56±0.09[a]	71.15±0.30[b]	15.53±0.13[a]	17.67±0.12[b]
			**	***	***	*	***

"Table 5 continued"

Sex by Age	F0PP1	23	5.41 ± 0.37^{e}	13.60 ± 0.24^{abc}	65.66 ± 0.84^{e}	13.22 ± 0.29^{g}	16.04 ± 0.45^{d}
	F1PPI	34	6.28 ± 0.32^{e}	13.99 ± 0.19^{ab}	67.83 ± 0.91^{e}	13.29 ± 0.24^{g}	17.22 ± 0.39^{cd}
	F2PPI	70	9.17 ± 0.32^{d}	14.08 ± 0.15^{ab}	71.53 ± 0.49^{d}	14.68 ± 0.23^{ef}	17.78 ± 0.18^{bc}
	F3PPI	88	10.93 ± 0.32^{c}	14.28 ± 0.13^{a}	74.12 ± 0.40^{bc}	15.54 ± 0.19^{de}	18.44 ± 0.18^{b}
	F4PPI	89	11.58 ± 0.35^{c}	14.12 ± 0.12^{ab}	74.00 ± 0.45^{bc}	15.82 ± 0.18^{cd}	18.71 ± 0.20^{b}
	M0PP1	73	7.23 ± 0.33^{e}	12.86 ± 0.14^{c}	67.09 ± 0.63^{e}	13.97 ± 0.28^{fg}	16.25 ± 0.20^{d}
	M1PPI	29	11.39 ± 0.17^{cd}	13.38 ± 0.23^{bc}	71.97 ± 0.88^{cd}	15.64 ± 0.20^{cde}	18.09 ± 0.35^{bc}
	M2PPI	27	15.77 ± 0.81^{b}	13.73 ± 0.24^{ab}	76.33 ± 0.29^{b}	17.06 ± 0.39^{bc}	19.01 ± 0.44^{b}
	M3PPI	28	20.11 ± 0.87^{a}	14.31 ± 0.27^{ab}	81.58 ± 0.83^{a}	18.93 ± 0.41^{a}	20.94 ± 0.36^{a}
	M4PPI	14	22.70 ± 1.17^{a}	14.67 ± 0.40^{a}	82.73 ± 1.60^{a}	18.83 ± 0.54^{ab}	21.77 ± 0.65^{a}
			***	*	***	**	**

Effect-level		N	RW	TL	NL
			LSM±SE	LSM±SE	LSM±SE
Over-all		475	16.64±0.12	16.10±0.09	29.6±0.18
R2			0.52	0.22	0.45
CV%			10.80	10.61	10.13
Sex	M	171	17.67 ± 0.25^{a}	16.95 ± 0.34^{a}	30 ± 0.16^{a}
	F	304	16.20 ± 0.11^{b}	15.64 ± 0.21^{b}	28.85 ± 0.10^{b}
			***	***	***
Age	0PPI	96	14.11 ± 0.19^{d}	15.09 ± 0.16^{d}	25.92 ± 0.35^{c}
	1PPI	63	15.32 ± 0.21^{c}	15.65 ± 0.24^{c}	27.95 ± 0.43^{bc}
	2PPI	97	17.04 ± 0.20^{b}	16.41 ± 0.18^{b}	29.59 ± 0.35^{ab}
	3PPI	116	18.66 ± 0.18^{a}	17.10 ± 0.19^{a}	32.06 ± 0.27^{a}
	4PPI	103	19.54 ± 0.22^{a}	17.25 ± 0.17^{a}	32.09 ± 0.35^{a}
			***	***	***
Agro-ecology	Highland	252	17.00 ± 0.12^{a}	16.79 ± 0.22^{a}	30.94 ± 0.12^{a}
	Lowland	223	16.87 ± 0.16^{a}	19.80 ± 0.22^{b}	28.11 ± 0.12^{b}
			Ns	***	***
Sex by age	F0PP1	23	14.45 ± 0.34^{ef}	14.85 ± 0.31^{d}	25.38 ± 0.89^{d}
	F1PPI	34	14.80 ± 0.20^{ef}	15.17 ± 0.31^{cd}	27.87 ± 0.52^{d}
	F2PPI	70	16.45 ± 0.22^{cd}	17.74 ± 0.20^{c}	28.40 ± 0.33^{cd}
	F3PPI	88	17.59 ± 0.17^{b}	16.37 ± 0.22^{b}	30.68 ± 0.28^{bc}
	F4PPI	89	17.70 ± 0.19^{b}	16.08 ± 0.16^{ab}	31.94 ± 0.38^{bcd}
	M0PP1	73	13.76 ± 0.22^{f}	15.33 ± 0.19^{d}	26.46 ± 0.36^{d}
	M1PPI	29	15.84 ± 0.36^{de}	16.13 ± 0.36^{cd}	28.03 ± 0.71^{bcd}
	M2PPI	27	17.64 ± 0.71^{bc}	17.09 ± 0.35^{b}	30.82 ± 0.85^{ab}
	M3PPI	28	19.74 ± 0.85^{a}	17.78 ± 0.29^{a}	33.44 ± 0.50^{a}
	M4PPI	14	21.40 ± 0.58^{a}	18.42 ± 0.58^{ab}	32.23 ± 1.04^{a}
			***	*	Ns

[a,b,c,d,e,f,g]*Means with different superscripts within the same column and class are statistically different; Ns= Non-significant; *significant at 0.05; **significant at 0.01; ***significant at p<0.001; N= Number of goats; LBW= Live body weight; BL= Body length; HG= Heart girth; WH= Wither height; PW= Pelvic width; HL= Horn length; EL= Ear length; RH= Rump height; CW= Chest width; RL= Rump length; RW= Rump width; TL= Tail length; NL= Neck length; 0PPI = 0 pair of permanent incisors; 1PPI= 1 pair of permanent incisor; ≥ 3PPI= 3 or more pairs of permanent incisors; LSM= Least square mean; SE= Standard error.*

Table 6. Coefficient of correlation between body weight and linear body measurement for Highland (above the diagonal female and below diagonal male) goat.

	LBW	HG	HW	BL	PW	HL	EL	RH	CW	RL	RW	NL	TL
LBW		0.96***	0.68***	0.81***	0.71***	0.56***	0.20*	0.66***	0.60***	0.52***	0.66***	0.65***	0.30***
HG	0.99***		0.64***	0.66***	0.70***	0.55***	0.19*	0.66***	0.60***	0.50***	0.67***	0.63***	0.27***
HW	0.94***	0.95***		0.61***	0.52***	0.45***	0.14ns	0.70***	0.47***	0.39***	0.54***	0.60***	0.35***
BL	0.94***	0.91***	0.88***		0.55***	0.49***	0.22*	0.54***	0.44***	0.48***	0.49***	0.54***	0.31***
PW	0.91***	0.92***	0.90***	0.85***		0.43***	0.16*	0.57***	0.50***	0.49***	0.69***	0.43***	0.30***
HL	0.91***	0.92***	0.85***	0.86***	0.85***		0.16*	0.51***	0.40***	0.30***	0.47***	0.39***	0.17*
EL	0.54***	0.54***	0.61***	0.53***	0.56***	0.48***		0.20*	0.11ns	0.14ns	0.18*	0.21**	0.09ns
RH	0.92***	0.93***	0.95***	0.88***	0.90***	0.85***	0.58***		0.52***	0.41***	0.63***	0.53***	0.38***
CW	0.87***	0.88***	0.85***	0.78***	0.86***	0.83***	0.46***	0.83***		0.38***	0.63***	0.46***	0.34***
RL	0.86***	0.85***	0.84***	0.82***	0.81***	0.78***	0.51***	0.80***	0.73***		0.45***	0.34***	0.29***
RW	0.90***	0.90***	0.85***	0.83***	0.86***	0.89***	0.47***	0.84***	0.82***	0.75***		0.46***	0.26**
NL	0.74***	0.73***	0.75***	0.72***	0.71***	0.61***	0.47***	0.74***	0.64***	0.66***	0.66***		0.22*
TL	0.69***	0.71***	0.75***	0.65***	0.69***	0.60***	0.50***	0.71***	0.60***	0.65***	0.64***	0.65***	

**** Correlation was significant at the 0.001 level (2- tailed); ** Correlation was significant at the 0.01 level and * Correlation was significant at the 0.05 level; LBW= Live body weight; HG= Heart girth; HW= Height at whether; BL= Body length; PW= Pelvic width; HL= Horn length; EL= Ear length; RH= Rump height; CW= Chest width; RL= Rump length; RW= Rump width; NL= Neck length; TL= Tail length.*

Table 7. Coefficient of correlation between body weight and linear body measurement for Lowland (above the diagonal female and below diagonal male) goat.

	LBW	HG	HW	BL	PW	HL	EL	RH	CW	RL	RW	NL	TL
LBW		0.97***	0.70***	0.89***	0.45***	0.58***	0.01ns	0.71***	0.63***	0.54***	0.64***	0.59***	0.19*
HG	0.98***		0.68***	0.77***	0.47***	0.58***	0.02ns	0.70***	0.65***	0.56***	0.64***	0.57***	0.22**
HW	0.84***	0.85***		0.67***	0.31***	0.44***	-0.02ns	0.75***	0.35***	0.44***	0.52***	0.48***	0.32**
BL	0.95***	0.91***	0.82***		0.38***	0.53***	-0.01ns	0.68***	0.48***	0.50***	0.57***	0.59***	0.17ns
PW	0.90***	0.89***	0.78***	0.87***		0.51***	0.27*	0.25***	0.44***	0.41***	0.41***	0.37***	0.18*
HL	0.90***	0.90***	0.79***	0.84***	0.82***		0.12ns	0.48***	0.47***	0.43***	0.41***	0.39***	0.24*
EL	0.42***	0.39***	0.43***	0.45***	0.44***	0.43***		0.07ns	0.03ns	0.02ns	0.02ns	-0.02ns	0.10ns
RH	0.90***	0.92***	0.84***	0.85***	0.82***	0.84***	0.36**		0.45***	0.53***	0.53***	0.58***	0.34**
CW	0.79***	0.79***	0.70***	0.76***	0.77***	0.70***	0.36**	0.76***		0.44***	0.58***	0.46***	0.05ns
RL	0.81***	0.82***	0.73***	0.78***	0.80***	0.75***	0.41***	0.80***	0.71***		0.48***	0.56***	0.27*
RW	0.89***	0.89***	0.80***	0.86***	0.85***	0.85***	0.42***	0.83***	0.79***	0.77***		0.51***	0.12ns
NL	0.80***	0.69***	0.60***	0.71***	0.71***	0.61***	0.34**	0.70***	0.64***	0.64***	0.62***		0.20*
TL	0.50***	0.59***	0.59***	0.59***	0.60***	0.57***	0.37***	0.60***	0.45***	0.62***	0.58***	0.41***	

****Correlation was significant at the 0.001 level (2- tailed); **correlation was significant at the 0.01 level (2-tailed); *Correlation was significant at the 0.05 level; LBW= Live body weight; HG= Heart girth; HW= Height at whether; BL= Body length; PW= Pelvic width; HL= Horn length; EL= Ear length; RH= Rump height; CW= Chest width; RL= Rump length; RW= Rump width; NL= Neck length; TL= Tail length.*

Estimation of Body Weight of Goats from Other Liner Body Measurements

Goat body weight is a very important characteristic in animal husbandry due to selection criteria and economic profit and making fortune for rural livestock enterprises. The accuracy of functions used to predict live weight or growth characteristics from live animal measurement is of immense financial contribution to livestock production enterprises (Afolayan *et al.,* 2006). Using measurements obtained readily and offering accurate prediction of body weight might be considered as a framework for recording systems in rural areas (Farhad *et al.,* 2013). Stepwise multiple linear regression analysis was used to obtain the best prediction equations for body weight from body measurement variables (Cam *et al.,* 2010). Hence, to predict body weight, linear body measurements like body length, height at wither, heart girth, rump length, rump height, chest width, horn length, ear length, and rump width were selected (Table 8). But for male goats, in addition to these, scrotum length and scrotum circumference were added. The linear body measurements were added one at a time to heart girth to evaluate the improvement of estimation. Parameter variables that best fitted the model were selected using the C (p) statistic, Adjusted R^2 (Adj. R-square), and SE (standard error). The small C (p) 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 explained by the model. The standard error (SE) usually decreases when new variables are added to the model but the addition of unnecessary variables to the model can increase the SE. In the current study, heart girth (HG) was the best predictor variable, which explains more variation than any other linear body measurements in both population and sexes. This is in agreement with the results of Tesfaye *et al.* (2008), Grum (2010), Halima *et al.* (2012), Mahilet (2012), Ahmed (2013), Belete (2013), Biruh (2013), Netsanet (2014), Alubel (2015) and Bekalu *et al.* (2016) as chest girth was selected first for prediction of live body weight of animals. The better association of body weight with chest girth was possibly due to relatively larger contribution to body weight of heart girth, which consists of bones, muscles, and viscera (Thiruvenkadan, 2005). Body length (BL) was the second selected predictor. Therefore, heart girth was a better predictor for calculating body weight under extensive management conditions. This also confirms earlier findings on the relationship between live weight and chest girth in sheep (Mengistie *et al.*, 2010; Shigdaf, 2011) and in goats (Netsanet, 2014; Yaekob *et al.*, 2015).

Table 8. Prediction equation of indigenous goat population in the study areas.

Population	Equation	Intercept	Regression coefficient				R^2	R^2Change	MSE
		α1	ß1	ß2	ß3	ß4			
Highland female	HG	-51.23	0.97				0.93	0.93	1.71
	HG+BL	-62.17	0.76	0.32			0.99	0.06	0.63
Highland male	HG	-64.61	0.99				0.99	0.97	2.22
	HG+BL	-69.05	0.77	0.25			0.99	0.01	1.71
	HG+BL+SL	-64.99	-0.76	0.24	-0.04		0.99	0.01	1.63
Lowland female	HG	-49.48	0.97				0.97	0.94	1.59
	HG+BL	-53.70	0.69	0.35			0.99	0.05	0.65
	HG+BL+RL	-53.33	0.71	0.36	-0.04		0.99	0.00	0.62
	HG+BL+RL+RH	-52.33	0.72	0.37	0.03	-0.02	0.99	0.00	0.61
Lowland male	HG	-55.88	0.98				0.98	0.97	2.11
	HG+BL	-58.79	0.72	0.29			0.99	0.01	1.56
	HG+BL+SL	-54.69	0.72	0.28	-0.05		0.99	0.00	1.44
	HG+BL+SL+SC	-54.14	0.71	0.29	0.04	0.03	0.99	0.00	1.40

HG= Heart girth; BL= Body length; SL= Scrotum length; RL= Rump length; RH= Rump height; SC= Scrotum circumference; MSE= Mean square error.

Conclusion

In conclusion, significant phenotypic variation was observed among goat populations in the study area, encompassing both qualitative and quantitative traits. The highland and lowland goat populations exhibited similar phenotypic characteristics, particularly with the central highland goat populations. However, there was no similarity found between the Begia-Medir goat and the current findings, raising questions about the former report. The highland goat population predominantly displayed patchy coat color patterns and red coat color, while the lowland goat population exhibited a plain coat color pattern with red and white colors. Additionally, both highland and lowland goats exhibited curved type horn shape. Short smooth hair type and semi-pendulum ear orientation were common traits among goats across the study areas. The highland goat population demonstrated higher linear body measurements and body weight compared to the lowland goat population. Factors such as sex, age, and the interaction between sex and age significantly influenced body weight and specific body measurements in both highland and lowland goat populations. Heart girth and body weight showed a strong positive correlation in both populations, with heart girth being the best predictor of body weight across sexes in the study areas.

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Conflict of Interests

The authors declare that they have no competing interests.

References

Afolayan, R.A., Adeyinka, I.A. & Lakpini, C.A.M. (2006). The estimation of live weight from body measurements in Yankasa sheep. *Czech Journal of Animal Science*, 51:343-348.

Ahmed Seid (2013). On-farm phenotypic and production system characterization of indigenous goats in Horro Guduru Wollega Zone, western Ethiopia, MSc Thesis, Haramaya University, Ethiopia.

Alade, N.K., Raji, A.O. & Atiku, M.A. (2008). Determination of appropriate model for the estimation of body weight in goats. *ARPN Journal of Agricultural and Biological Science,* 3 (4): 52-57.

Alubel Alemu (2015). On-farm phenotypic characterization and performance evaluation of Abergelle and Central Highland goat breeds as an input for designing community-based breeding program, MSc Thesis, Haramaya University, Ethiopia.

Bekalu Muluneh, Kefelegn Kebede & Yoseph Mekasha (2016). Characterization of indigenous goat breeding practices and production system in West Gojjam Zone, Amhara National Regional State, Ethiopia. *Journal of Natural Sciences Research*, 6 (5): 67-75.

Belete Asefa (2013). On farm phenotypic characterization of indigenous goat types and their production system in Bale Zone of Oromia Region, Ethiopia, MSc Thesis, Haramaya University, Ethiopia.

Biruh Tesfahun (2013). Phenotypic and production system characterization of Woyto-Guji goats in lowland areas of south Omo Zone, MSc Thesis, Haramaya University, Ethiopia.

Cam, M.A., Olfaz, M. & Soydan, E. (2010). Possibilities of using morphometric characteristics as a tool for body weight prediction in Turkish hair goats (Kilkeci). *Asian Journal of Animal and Veterinary Advances*, 5 (1):52–59.

Cochran, W.G. (1977). Sampling techniques, 3rd ed., Wiley and Sons, New York.

CSA (Central Statistical Agency) (2013). Agricultural sample survey report on livestock and livestock characteristics, Vol. II, Statistical Bulletin 570, Addis Ababa, Ethiopia.

CSA (Central Statistical Agency) (2021). Federal Democratic Republic of Ethiopia Agricultural Sample Survey Report on Livestock and Livestock Characteristics: Private Peasant Holdings, Vol. II, Statistical Bulletin 589, Addis Ababa, Ethiopia.

Dereje Tsegaye, Berhanu Belay & Aynalem Haile (2013). Morphological characterization of indigenous Hararghe Highland goat breed in their native environment, West Hararghe, Ethiopia. *American-Eurasian Journal of Scientific Research*, 8 (2): 72-79. DOI: 10.5829/idosi.aejsr.2013.8.2.7267.

FAO (Food and Agricultural Organization of the United Nations) (2007). The global plan of action for animal genetic resources and the interlaken declaration on animal genetic resources. International technical conference on animal genetic resources for food and agriculture, Interlaken, Switzerland, held from 3-7 September, 2007.

FAO (Food and Agricultural Organization of the United Nations) (2012). Phenotypic characterization of animal genetic resources. FAO Animal Production and Health Guidelines No.11, Rome, Italy.

FAOSTAT (2016). Food and agricultural organization of the United Nations, database. Accessed on 8 February, 2016.

Farhad Hosseinzadeh Shirzeyli, Abolghasem Lavvaf & Asad Asadi (2013). Estimation of body weight from body measurements in four breeds of Iranian sheep. *Songklanakarin Journal of Science and Technology*, 35 (5): 507-511.

FARM-Africa (1996). Goat types of Ethiopia and Eritrea: Physical description and management systems. Published jointly by FARM-Africa, London, UK, and ILRI (International Livestock Research Institute), Nairobi, Kenya.

Frandson, R.D. & Elmer, H.W. (1981). Anatomy of the male reproductive system. In: R.D. Frandson (Ed.), Anatomy and physiology of farm animals, 3rd ed., Lea and Febiger, Philadephia, pp: 430-442.

Getinet Mekuriaw Tarekegn (2016). Molecular characterization of Ethiopian indigenous goat populations: Genetic diversity and structure, demographic dynamics and assessment of the kisspeptin gene polymorphism, PhD Dissertation, Addis Ababa University, Ethiopia.

Grum Gebreyesus (2010). Community-based participatory characterization of the Short-Eared Somali goat population around Dire Dawa, MSc Thesis, Haramaya University, Ethiopia.

Grum Gebreyesus, Aynalem Haile & Tadelle Dessie (2014). Evaluation of growth trends in the Short-eared Somali goat breed of eastern Ethiopia. *Research Journal of Applied Sciences*, 9 (5): 224-227.

Hagan, J.K., Apori, S.O., Bosompem, M., Ankobea, G. & Mawuli, A. (2012). Morphological characteristics of indigenous goats in the Coastal Savannah and forest eco-zones of Ghana. *Journal of Animal Science Advances*, 2 (10): 813-821.

Halima Hassen, Michael Baum, Barbara Rischkowsky & Markos Tibbo M. (2012). Phenotypic characterization of Ethiopian indigenous goat populations. *African Journal of Biotechnology,* 11 (73): 13838-13846.

Hussein Toyib (2015). On-farm phenotypic characterization and breeding practices of Arsi-Bale goat population in selected districts of Arsi and Bale Zones, Oromia Regional State, Ethiopia, MSc Thesis, Bahir Dar University, Ethiopia.

Jimmy, S., David, M., Donald, K.R. & Dennis, M. (2010). Smallholder goat breeding systems in humid, sub-humid and semi-arid agro-ecological zones of Uganda. *Global Veterinaria*, 4 (3): 283-291.

Kassahun Awgichew & Solomon Abegaz (2008). Breeds of sheep and goats. In: Alemu Yami & R.C. Merkel (Eds.), Sheep and goat production handbook for Ethiopia, Ethiopian Sheep And Goat Productivity Improvement Program, USAID, pp: 5-26.

Mahilet Dawit (2012). Characterization of Hararghe Highland goat and their production system in Eastern Hararghe, MSc Thesis, Haramaya University, Ethiopia.

Mengistie Taye, Girma Abebe, Solomon Gizaw, Sisay Lemma, Abebe Mekoya & Markos Tibbo (2010). Traditional management systems and linear body measurements of Washera sheep in the western highlands of the Amhara National Regional State, Ethiopia. *Livestock Research for Rural Development,* 22 (9).

Netsanet Zergaw (2014). On-farm phenotypic characterization and performance evaluation of Central Highland and Woyto-Guji goat types for designing community-based breeding strategies in Ethiopia, MSc Thesis, Haramaya University, Ethiopia.

Nottor, D.R. (2012). Genetic improvement of reproductive efficiency of sheep and goat. *Animal Reproduction Science,* 130:147-151.

Okbeku, M., Yakubu, A., Peters, S.O., Ozoje, M.O., Ikeobi, C.O., Adebambo, O.A. & Imumorin, I.G. (2011). Application of multivariate principal component analysis to morphological characterization of indigenous goats in southern Nigeria. *Acta Argiculturae Slovenica*, 98 (2): 101–109.

SAS (Statistical Analysis System) (2013). SAS for windows, Release 9.40., SAS Institute, Inc., Cary, NC, USA.

Seifemichael Melaku, Kefelegn Kebede, Negassi Amha & Banerjee, A. K. (2014). Variability in linear body measurements and their application in predicting body weight of Afar goats in Ethiopia. *International Journal of Interdisciplinary and Multidisciplinary Studies*, 1 (4): 17-25.

Semakula, J., Mutetikka, D., Kugonza, R.D. and Mpairewe. D. (2010). Variability in body morphometric measurements and their application in predicting live body weight of Mubende and Small East African goat breeds in Uganda. *Middle-East Journal of Scientific Research,* 5 (2): 98-105.

Shigdaf Mekuriaw (2011). Performance Evaluation of Washera, Farta and their crossbred sheep in western highlands of Amhara Region, Ethiopia, MSc Thesis, Bahir Dar University, Ethiopia.

Solomon, A., Workalemahu, A., Jabbar, M. A., Ahmed, M.M. & Hurissa, B. (2003). Livestock marketing in Ethiopia: A review of structure, performance and development initiatives. Socio-economic and policy research working paper 52, International Livestock Research Institute (ILRI), Nairobi, Kenya.

Solomon Abegaz Guangul (2014). Design of community based breeding programs for two indigenous goat breeds of Ethiopia, PhD Thesis, BOKU-University of Natural Resources and Life Sciences, Vienna, Austria.

Sowande, O.S., Oyewale, B.F. & Iyasere O.S. (2009). Age and sex dependent regression models for predicting the live weight of West African Dwarf goat from body measurements. *Tropical Animal Health and Production*, 42: 969-975.

Tadesse, D., Urge, M., Animut, G. & Mekasha, Y. (2013). Perceptions of households on purpose of keeping, trait preference and production constraints for selected goat types in Ethiopia. *Tropical Animal Health and Production,* 46 (2): 363-70. DOI 10.1007/s11250-013-0497-x.

Tesfaye Kebede, Tesfaye Lemma, Hunduma Dinka, Mieso Guru & Amsalu Sisay (2008). Growth performance and carcass characteristics of Arsi-Bale goats castrated at different ages. *Journal of Cell and Animal Biology,* 2 (11): 187-194.

Tesfaye Tsegaye (2009). Characterization of goat production systems and on-farm evaluation of the growth performance of grazing goats' supplemented with different protein sources in Metema *woreda*, Amhara Region, Ethiopia, MSc Thesis, Haramaya University, Ethiopia.

Tilahun, H. & Schmidt, E. (2012). Spatial analysis of livestock production patterns in Ethiopia. ESSP II Working Paper 44, International Food Policy Research Institute/Ethiopia Strategy Support Program II, Addis Ababa, Ethiopia.

Thiruvenkadan, A. K. (2005). Determination of best-fitted regression model for estimation of body weight in Kanni Adu kids under farmer's management system. *Livestock Research for Rural Development*, 17 (7).

Tsigabu Gebreselassie (2015). Phenotypic characterization of goat type and their husbandry practices in Nuer Zone of Gambella People Regional State, southwestern Ethiopia, MSc Thesis, Haramaya University, Ethiopia.

Yaekob Lorato, Kirman Manzoor Ahmed & Birhanu Belay (2015). Morphological characterization of indigenous Woyto-Guji goat breed in Loma district, southern Ethiopia, MSc Thesis, Jimma University, Ethiopia.

Yoseph Mekasha (2007). Reproductive traits in Ethiopian male goats, with special reference to breed and nutrition, PhD Dissertation, Swedish University of Agricultural Science (SLU), Uppsala, Sweden.