Multivariate characterization of Wollo sheep populations in the cool highlands of Ethiopia

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Abstract

The objective of this study was to assess variation among populations of Wollo sheep managed in different locations. Three locations were selected purposely based on their sheep population size, sheep production potential and experiences of farmers in sheep breeding. Body weight, linear body measurements and qualitative data were recorded from a total 405 sheep (322 females and 83 males) in 68 flocks. Body weight and most of the linear body measurements of the indigenous sheep populations were significantly affected by location (p<0.05). The stepwise discriminant analysis procedure identified eight most significant discriminating traits: rump height (RH), wither height (WH), body weight (BW), tail circumference (TC), body condition score (BCS), ear length (EL), chest girth (CG) and body length (BL) from females; and five: RH, BW, WH, BL and horn length (HL) from males. The overall average error count estimate of sheep was 30%, accounting for 44%, 33% and 14% for Wogide, Borena and Legambo sheep populations, respectively. This means that 70% of sheep for all populations were correctly classified in their source population. In conclusion, the lowest misclassification of Legambo sheep population could be an indication of more uniformity within the population, whereas the highest misclassification of Wogide and Borena might be due to low geographical distance between their habitats. The largest distance was found between the Wogide and Legambo sheep populations and between the Borena and Legambo sheep populations, whilst the sheep populations from the Wogide and Borena were poorly differentiated. More genetic analysis research is recommended to assess variations and similarities of sheep and to identify the potential of genetic resources.

Keywords: Indigenous sheep; Linear-measurements; Morphological traits; Multivariate analysis.

Introduction

Ethiopia has 31.3 million sheep, and sheep play a significant role in the livelihood of rural communities of Ethiopia (CSA, 2018). Ethiopia is home for at least 9 breeds and 14 traditional sheep populations (Gizaw *et al*., 2007). The country has about 14 varied traditional sheep populations in four major groups i.e., sub-alpine short fat-tailed, highland long fat-tailed, lowland fat-rumped/tailed, and lowland thin-tailed (Gizaw *et al.,* 2008). Wollo sheep population is among the sub-alpine short fat-tailed group predominantly found in the central highlands at an altitude of ≥2500 m above sea level. Sub-alpine short fat-tailed sheep are mainly reared for income generation from the sale of lambs at market age, although they are also important as a source of food, hair, manure and socio-cultural benefits (Gizaw *et al.,* 2008; Getachew *et al.,* 2010).

Breed diversity is high in peripheral and remote areas of the country (Gizaw *et al.,* 2008) due to less human intervention for crossing. Similarly, sheep are adapted to various ecological niches and the differing needs and preferences of their breeders who belong to different ethnic communities. High phenotypic diversity for morphological characteristics, significant within and between breeds, was observed in sheep found in the country (Gizaw *et al.,* 2007, Getachew *et al*., 2009; Michael *et al*., 2016).

Body measurements have been used to predict body weight by several authors in many breeds of sheep (Sowande and Sobola, 2007; Cankaya, 2008; Iqbal, 2010; Michael *et al*., 2016). The use of multivariate analysis to classify different goat (Zaitoun *et al*., 2005; Dossa *et al*., 2007) and sheep (Riva *et al*., 2004; Traore *et al.,* 2008) populations, based on various qualitative and quantitative measurements, has also been reported. When all measured morphological characteristics are taken into account at the same time, this can be thought of as an appropriate instrument for evaluating population variance and discriminating between distinct population types.

In general, there is information gap regarding the phenotypic characteristics of Wollo sheep populations since, the overall local sheep morphological characteristics were not studied at the district level. Accordingly, there hasn't been any research on morphological characterization of sheep, including body weight, in Wogide, Borena and Legambo districts, and no research has been conducted to identify the genetic resources of sheep in the districts. It is important to identify the sheep genetic resources potential of the areas, as the information may be used to establish breeding programs and to conserve the genetic resources. It is also necessary to understand the breeding practices and breeding objectives of farmers. Hence the aim of this study was to assess the variation of Wollo sheep populations using multivariate analysis to understand the potential of sheep in the specific places.

Materials and methods

Description of the study area

The study was conducted in three selected districts of South Wollo zone of the Amhara Regional State, namely Wogide, Borena, and Legambo districts. Wogide is bordered by Woleka River to the south, which separates it from the Oromia Region; by the Abay River to the west which separates it from East Gojjam zone; by Borena district to the north; by Legambo to the northeast and by Kelala district to the east. Borena is bordered by Wogide to the south, by the Abay River to the west which separates it from the East Gojjam zone, by Mehal-Sayint to the north, by Sayint to the northeast, and by Legambo to the east. Legambo is bordered by Legehida and Kelala to the south, by Wogide to the southwest, by Borena to the west, by Sayint-Ajibar to the northwest, by Tenta to the north, by Dessie Zuria to the east, and by Woreilu to the south-east. The capital town of Legambo is Akesta (CSA, 2008). The geographic co-ordinate points, rainfall, and temperature of the study districts are presented in Table 1.

Table 1. Description of the districts.

Characteristics of the study area	Districts		
	Wogide	Borena	Legambo
Latitude and longitude	10°40′N, 11°38′E	10°55′N, 38°30′E	11°00′N, 39°00′E
Rainfall (mm)	600 to 1100	1500 to 3660	700 to 1200
Temperature	23 °C	16.5 °C	13 °C
Area (km^2)	1,110.69	1,027.61	1,017.35
Sheep population	15,442	68,642	146,954

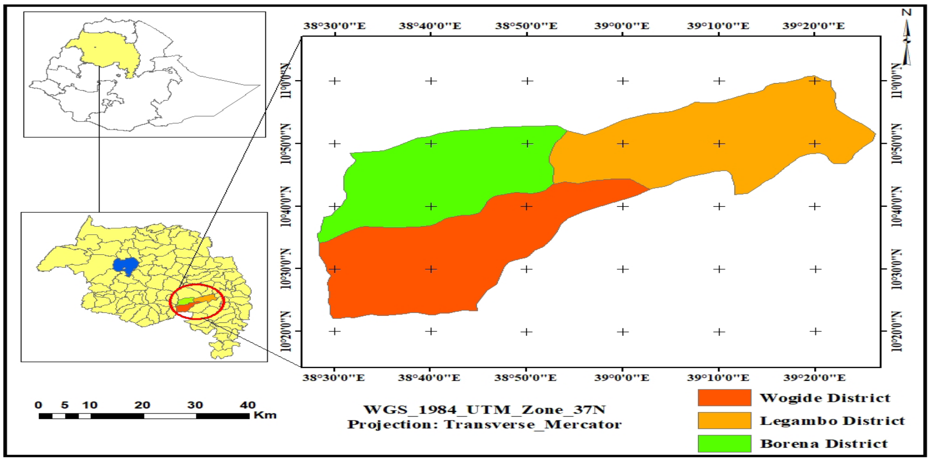

Figure 1. Map of the study area.

Animal sampling and body measurements

For qualitative and quantitative data collection purpose, animals were restrained and held in a natural position. The body weight and linear measurements were taken using a measuring tape and a measuring stick early in the morning before the animals were fed to avoid biases on certain traits due to feed intake. A total of 405 sheep (322 female and 83 male) were sampled from the study areas. The number of animals sampled per site is presented in Table 2. Five to 7 animals in each flock were used for body measurements and observation in order to avoid sampling of related animals.

Sampling techniques

Three districts were selected purposely from South Wollo zone based on their sheep population size, sheep production potential, and farmers' experience in sheep rearing. Three kebeles from each Wogide and Borena districts and two Kebeles from Legambo district (a total of 8 Kebeles) were selected based on their sheep production potential and road accessibility. *Kebele is* the lowest administrative hierarchy in Ethiopia.

Physical measurements were taken according to FAO (2012) guidelines, from a representative set of adult animals (as judged by dentition of 0PPI to ≥2PPI): 100-300 for females and 10-30 for males. Body weight and linear body measurements were obtained from a total of 405 sheep (322 female and 83 male). Within each Kebele, measurements were made on individual indigenous sheep from randomly selected flocks.

Table 2. Distribution of samples across district and kebele.

Locations	*Kebele*	Samples	Total per district
Wogide	Seka-Shimbira	45	135
	Abado	45	
	Makefta	45	
Borena	Deramie	50	150
	Hulagosh	50	
	Chefe Belo	50	
Legambo	Dembesh	60	120
	Temu	60	

Methods of data collection

Qualitative data collection

Visual observations for qualitative traits were made and morphological features were recorded based on breed morphological characteristics descriptor list of phenotypic characterization of sheep. Generally six qualitative traits were observed like coat color pattern (plain, patch, spotted), coat hair type (short and smooth, long and coarse and short and coarse), coat color type (white, red, black, red and white, black and white, black with white head, ark grey /Jibma/, black with red/white belly and brown), head profile (straight/flat, concave and convex), ear formation (rudimentary, short/inclined downward and dropping/semi pendulous), and horn (present and absent) (FAO, 2012).

Quantitative data collection

Quantitative traits cover the size and dimensions of animals' bodies or body parts, which are more directly correlated to production traits than are qualitative traits. The body measurements collected were body weight (BW), chest girth (CG), body length (BL), wither height (WH), tail length (TL), tail circumference (TC), rump height (RH), ear length (EL), horn length (HL), scrotal circumference (SC) and body condition score (BCS). Linear body measurements were made using measuring tape while live body weight was taken using suspended spring balance having 50 kg capacity with 0.2 kg precision.

Each animal was identified by its sex, dentition (0PPI, 1PPI and ≥2PPI) and sampling site. A dentition record was included, as this was the only reliable means to estimate the approximate age of an animal. The ages of the animals were estimated from dentition class following the procedure described by ESGPIP (2009). Adult sheep were classified into three age groups: no pair of permanent incisors (0PPI), 1 pair of permanent incisors (1PPI), 2 pairs of permanent incisors and above (≥ 2PPI), to represent age of sheep below 12 months, 12 to 18 months, 18 to 24 months and more than two years, respectively based on ESGPIP (2009).

Multivariate analysis

In order to ascertain the assignment (%) of each individual animal, identify significant discriminative traits, obtain distances between sample populations, and observe the spatial distribution of sample populations, multivariate discriminant analysis was carried out using quantitative traits for locations of sheep (Aziz and Al-Hur, 2012; FAO, 2012). Stepwise discriminant analysis, percent classified into each location for populations using discriminant analysis squared mahalanobis distances between sampled populations based on pooled covariance were analyzed by using quantitative traits of female and male sheep.

Data management and statistical analysis

Data collected through body measurement were entered into Microsoft EXCEL 2007. The data collected from each study area were checked for any errors, coded, and entered into computer for further analysis. Preliminary data analysis like homogeneity test, normality test and screening of outliers were carried out using PROC UNIVARIATE in Statistical Analysis System (SAS) before conducting the main data analysis. Observations on morphological characters were analyzed for male and female sheep using frequency procedure of SAS (SAS version 9.1, 2003). Quantitative characters (body weight and linear body measurements) were analyzed using the Generalized Linear Model (GLM) procedures of the SAS (SAS 9.1, 2003). Scrotum circumference was analyzed for each population by fitting age group as fixed factor. When analysis of variance declares significance, least square means were separated using adjusted Tukey-Kramer test.

The model to analyze adult body weight and other linear body measurements for indigenous sheep except scrotum circumference was**:**

Yijk =µ + Ai + Lj +Sk + (AxS) ik + eijk

Where: Y*ijkl*= the body weight and linear body measurements except scrotum circumference in the i^{th}age group, j^{th} location and k^{th} sex

µ = overall mean
Ai = the effect of i^{th} age group (*i = 0, 1and* ≥2 dentition)
Lj = the effect of j^{th} location (j = Wogide, Borena and Legambo)
Sk = the effects of k^{th} sex (k= male, female)
(AxS) ik = the effect of the interaction of *i* of age group with *k* of sex
Eijk = random residual

Results

Qualitative traits

Summary of qualitative traits observed in indigenous male and female sheep by district is presented in Table 3. In the study areas, sheep were short fat tailed (100%), and the tail was curved upward at the tip (96.79%), the remaining small proportion was straight and tip downward.

Table 3. Frequency and percentage of each class level of the qualitative traits scored in Wollo sheep.

Qualitative traits	Locations												Overall	
	Wogide (N = 135)				Borena (N = 150)				Legambo (N = 120)					
	Male		Female		Male		Female		Male		Female			
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Coat color pattern														
Plain	17	56.7	79	75.2	22	73.3	75	62.5	18	78.3	71	73.2	282	69.63
Patchy	8	26.7	16	15.2	7	23.3	41	34.2	4	17.4	23	23.7	99	24.44
Spotted	5	16.7	10	9.5	1	3.3	4	3.3	1	4.3	3	3.1	24	5.93
Coat hair type														
Short and smooth	2	6.7	1	1.0	-	-	-	-	-	-	-	-	3	0.74
Long and coarse	25	83.3	99	94.3	28	93.3	120	100.0	23	100.0	93	95.9	388	95.80
Short and coarse	3	10.0	5	4.7	2	6.7	-	-	-	-	4	4.1	14	3.46
Coat color type														
White	8	26.7	48	45.7	13	43.3	47	39.2	11	48.7	38	39.2	165	40.74
Red	2	6.7	9	8.6	2	6.7	14	11.7	4	17.4	15	15.5	46	11.36
Black	5	16.7	7	6.7	5	16.7	12	10.0	3	13.0	18	18.6	50	12.35
Red and white	2	6.7	3	2.9	2	6.7	2	1.7			3	3.1	12	2.96
Black and white	3	10.0	5	4.8	-	-	8	6.7	2	8.7	5	5.2	23	5.68
Black with white head	-	-	3	2.9	-	-	1	0.8			1	1.0	5	1.23
Dark grey/ Jibma/	8	26.7	14	13.3	2	6.7	22	18.0	2	8.7	10	10.3	58	14.32
Black with red/ white belly	-	-	1	1.0	1	3.3	-	-	-	-	-	-	2	0.49
Brown	2	6.7	15	14.3	5	16.7	14	11.7	1	4.3	7	7.2	44	10.86
Head profile														
Straight/flat	23	76.7	71	67.6	21	70.0	94	78.3	19	82.6	68	70.1	296	73.09
Concave	2	6.7	4	3.8	1	3.3	6	5.0	2	8.7	5	5.2	20	4.94
Convex	5	16.7	30	28.6	8	26.7	20	16.7	2	8.7	24	24.7	89	21.98
Ear formation														
Rudimentary	2	6.7	11	10.5	2	6.7	6	5.0	1	4.3	3	3.1	25	6.17
Short/inclined downward	13	43.3	27	25.7	9	30.0	15	12.5	1	4.3	4	4.1	69	17.04
Dropping/ semi pendulous	15	50.0	67	63.8	19	63.3	99	82.5	21	91.3	90	92.8	311	76.79
Horn														
Present	30	100.0	10	9.5	30	100.0	17	14.2	23	100.0	4	4.1	114	28.15
Absent	-	-	95	90.5	-	-	103	85.8	-	-	93	95.9	291	71.85

N: numbers of observations

Quantitative traits

Body weight, body length, chest girth, tail length, ear length, and rump height in Wogide and Borena sheep populations were not statistically different ($p > 0.05$), but statistically different ($p < 0.05$) from Legambo sheep population. The overall body weight of Wogide, Borena and Legambo sheep populations were 24.90±0.38, 25.71±0.39 and 22.19±0.41 whereas the chest girth were 70.18±0.46, 70.67±0.47 and 64.16±0.50, respectively.

Association of quantitative traits with fixed factors

The effect of location, sex, age group and interaction of age group and sex on body weight and other linear body measurements are presented in Table 4. In this study, body weight and most of the linear body measurements (body length, chest girth, wither height, tail length, tail circumference, rump height and ear length) were significantly ($p < 0.01$) affected by location. Body condition score was also affected ($p < 0.05$) by location, whereas horn length and scrotum circumference were not influenced by location ($p > 0.05$).

Table 4. Least squares means ± standard errors of body weight (kg), linear body measurements (cm) for the effects of locations, sex, age group and sex by age group for indigenous sheep in the study areas.

Effects & levels		BCS	BW	BL	CG	WH	TL	TC	EL	RH	HL	SC
	N	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE	LSM±SE
Overall	405	2.71±0.04	24.27±0.28	54.04±0.28	68.34±0.34	62.16±0.28	21.49±0.22	20.88±0.23	8.70±0.13	66.52±0.26	13.87±0.84	24.38±0.35
Locations		*	**	**	**	**	**	**	**	**	NS	NS
Wogide	135	2.69±0.06^{ab}	24.90±0.38^{a}	55.69±0.38^{a}	70.18±0.46^{a}	63.42±0.38^{b}	22.09±0.29^{a}	21.45±0.31^{a}	9.03±0.18^{a}	69.45±0.36^{a}	13.42±1.12	24.74±0.52
Borena	150	2.82±0.06^{a}	25.71±0.39^{a}	55.40±0.39^{a}	70.67±0.47^{a}	65.45±0.38^{a}	21.67±0.30^{a}	21.02±0.32^{ab}	9.33±0.18^{a}	69.44±0.36^{a}	13.61±0.99	23.83±0.54
Legambo	120	2.61±0.06^{b}	22.19±0.41^{b}	51.03±0.41^{b}	64.16±0.50^{b}	57.60±0.40^{c}	20.74±0.32^{b}	20.19±0.34^{b}	7.72±0.19^{b}	60.67±0.38^{b}	14.59±1.42	24.57±0.64
Sex		**	**	NS	**	**	**	**	NS	**	**	NA
Male	83	2.88±0.07^{a}	26.09±0.47^{a}	54.46±0.47	69.50±0.57^{a}	63.66±0.46^{a}	22.63±0.36^{a}	23.12±0.38^{a}	8.62±0.22	68.19±0.44^{a}	21.47±0.73^{a}	24.38±0.35
Female	322	2.54±0.05^{b}	22.46±0.31^{b}	53.62±0.30	67.17±0.37^{b}	60.64±0.30^{b}	20.37±0.24^{b}	18.65±0.25^{b}	8.78±0.14	64.85±0.29^{b}	6.23±1.48^{b}	-
Age group		*	**	**	**	**	**	**	**	**	**	**
0PPI	137	2.71±0.05^{ab}	19..65±0.35^{c}	49.65±0.35^{c}	63.68±0.43^{c}	58.77±0.35^{c}	20.00±0.27^{b}	19.74±0.29^{b}	8.30±0.16^{b}	63.05±0.33^{c}	9.32±1.19^{b}	20.50±0.42^{c}
1PPI	46	2.55±0.09^{b}	25.00±0.58^{b}	55.10±0.57^{b}	69.00±0.70^{b}	62.77±0.57^{b}	21.58±0.44^{a}	20.77±0.47^{ab}	8.56±0.27^{ab}	67.23±0.54^{b}	15.77±1.86^{a}	24.54±0.63^{b}
≥2PPI	222	2.86±0.08^{a}	28.17±0.51^{a}	57.36±0.50^{a}	72.33±0.61^{a}	64.93±0.50^{a}	22.92±0.39^{a}	22.15±0.41^{a}	9.22±0.23^{a}	69.29±0.47^{a}	16.46±1.03^{a}	28.05±0.72^{a}
Sex by age		**	**	NS	**	**	**	**	NS	**	**	NA
Male 0PPI	46	2.67±0.09	20.24±0.57^{cd}	49.73±0.57	63.31±0.69^{c}	59.16±0.56$_{de}$	20.47±0.44^{bc}	20.69±0.47^{b}	8.31±0.26	63.78±0.54^{de}	13.22±0.88^{b}	-
Male 1PPI	21	3.03±0.13	27.72±0.85^{ab}	55.35±0.84	71.26±1.03^{a}	64.41±0.84^{ab}	22.62±0.65^{ab}	23.36±0.69^{a}	8.18±0.39	68.89±0.79^{ab}	25.21±1.31^{a}	-
Male ≥2PPI	16	2.93±0.15	30.31±0.98^{a}	58.31±0.97	73.94±1.18^{a}	67.41±0.96^{a}	24.79±0.75^{a}	25.31±0.79^{a}	9.38±0.45	71.91±0.91^{a}	25.99±1.50^{a}	-
Female 0PPI	91	2.75±0.06	19.04±0.41^{d}	49.58±0.41	64.04±0.49^{bc}	58.38±0.40^{e}	19.53±0.31^{c}	18.78±0.33c	8.30±0.19	62.32±0.38^{e}	5.53±2.20^{c}	-
Female 1PPI	25	2.07±0.12	22.28±0.78^{c}	54.86±0.77	66.75±0.94^{b}	61.13±0.77^{cd}	20.53±0.60^{bc}	18.18±0.64^{c}	8.98±0.36	65.57±0.73^{cd}	6.34±3.46^{bc}	-
Female≥2PPI	206	2.79±0.04	26.04±0.27^{b}	56.41±0.27	70.72±0.33^{a}	62.42±0.27^{bc}	21.04±0.21^{b}	18.99±0.22^{c}	9.07±0.13	66.67±0.26^{bc}	6.93±1.38^{c}	-

Means with different superscripts within the same column and class are statistically different. Ns: Non-significant; *significant at 0.05; **significant at 0.01; NA: none applicable; N: number of sheep; BCS: body condition score; BW: body weight; BL: body length; CG: chest girth; WH: wither height; TL: tail length; TC: tail circumference; EL: ear length; RH: rump height; HL: horn length; SC: scrotum circumference; 0PPI: 0 pair of permanent incisor; 1PPI: 1 pair of permanent incisor; ≥2PPI: 2 or more pairs of permanent incisors; LSM: least square mean; SE: standard error.

Multivariate analysis

The stepwise discriminant analysis procedure identified eight (RH, WH, BW, TC, BCS, EL, CG, and BL) most significant discriminating traits between females while five discriminating traits (RH, HL, BW, WH and BL) were identified in males. Table 5 illustrates how each predictor for both sexes increased the discriminant function's predictive power between sample populations. Each predictor's association with Wilk's Lambda and Average Squared Canonical Correlation was statistically significant (*p* <0.05) for each variable. Percent of classification into each location for populations using discriminant analysis is presented in Table 6. Squared Mahalanobis distances between sampled populations based on pooled covariance are shown in Table 7. Every sheep pairwise distance was statistically significant (*p*<0.05).

Table 5. Quantitative characters selected by stepwise discriminant analysis.

Sex	Step	Variable	Partial R^2	F value	Pr>r	Wilks' lambda	Pr< lambda	ASCC	Pr> ASCC
Female	1	Rump height	0.545	191.38	<.0001	0.455	<.0001	0.273	<.0001
	2	Wither height	0.102	18.06	<.0001	0.408	<.0001	0.324	<.0001
	3	Body weight	0.063	10.65	<.0001	0.383	<.0001	0.338	<.0001
	4	Tail circumference	0.046	7.68	0.0006	0.365	<.0001	0.351	<.0001
	5	Body condition score	0.034	5.53	0.0044	0.352	<.0001	0.361	<.0001
	6	Ear length	0.042	6.87	0.0012	0.338	<.0001	0.374	<.0001
	7	Chest girth	0.019	2.98	0.0522	0.331	<.0001	0.377	<.0001
	8	Body length	0.014	2.20	0.1121	0.327	<.0001	0.383	<.0001
Male	1	Rump height	0.425	29.52	<.0001	0.575	<.0001	0.212	<.0001
	2	Horn length	0.359	22.15	<.0001	0.369	<.0001	0.316	<.0001
	3	Body weight	0.111	4.89	0.0101	0.328	<.0001	0.349	<.0001
	4	Wither height	0.191	9.10	0.0003	0.265	<.0001	0.419	<.0001
	5	Body length	0.089	3.71	0.0290	0.241	<.0001	0.446	<.0001

ASCC: Average Squared Canonical Correlation

Table 6. Percent classified into each location for populations using discriminant analysis.

Locations	Wogide	Borena	Legambo	Total
Wogide	56.30	33.33	10.37	100
Borena	28.00	66.67	5.33	100
Legambo	5.00	9.17	85.83	100
Total	30.62	38.52	30.86	100
Error rate	0.44	0.33	0.14	0.30

Table 7. Squared Mahalanobis distances between sampled populations based on pooled covariance.

Locations	Wogide	Borena	Legambo
Wogide	**		
Borena	0.83	**	
Legambo	6.84	6.76	**

Discussion

Qualitative traits

In the study areas, sheep were short fat tailed (100%), and the tail was curved upward at the tip (96.79%), the remaining small proportion was straight and tip downward. This finding was in agreement with observations of that of Gizaw *et al.* (2008) for Wollo sheep, Getachew *et al.* (2009) for Menz sheep, Mohammed *et al.* (2014) for sheep in Habru and Gubalafto districts of North Wollo zone and Bimerow *et al.* (2011) for Farta sheep, all of whom reported short fat tail type for the respective sheep populations they studied.

About 69.63% of the sheep had plain coat colour pattern, 24.44% patchy and 5.93% spotted. The current result was in line with Bireda *et al.* (2016) who reported that majority of the sheep in Gode and Adadile districts also had plain coat colour pattern. About 95.80% of indigenous sheep in the study areas had long and coarse hair, while only 3.46% and 0.74% had short and coarse, and short and smooth (0.74) hair, respectively. The present result is in agreement with Getachew *et al.* (2009), who reported a 98.80% long and coarse hair for Menz sheep. As indicated in coat colour preferences ranking, black coat colour had the least preference among the wide ranges of coat colours and this was confirmed by small proportions of animals exhibiting black coat colour in the sampled population. This finding was similar to the findings of Edea *et al.* (2009) and Bireda *et al.* (2016) who reported least preference to black coat color for Bonga and Horro sheep and for Gode and Adadile sheep rearing areas, respectively.

Quantitative traits

Body weight and most of the linear body measurements (body length, chest girth, wither height, tail length, tail circumference, rump height and ear length) were significantly (p <0.05) affected by location. Body condition score was also affected (p <0.05) by location, whereas horn length and scrotum circumference were not influenced by locations. This result was in line with the findings of Amelmal (2011) and Michael *et al.* (2016), who reported significant differences (p <0.05) in most of the linear body measurements and live body weight in the study areas. But the present result contradicts with a report by Shibabaw (2012) which indicated that location had no effect (p >0.05) on body measurements, except on body weight which was higher in Metta (29.4±0.2) than Deder (28.8±0.2) district in Hararge highland sheep.

In this study, most of the linear body measurements of the Wogide and Borena sheep population were almost similar but higher than sheep in Legambo areas. For example the rump height of Wogide and Borena sheep were 69.45±0.36 and 69.44±0.36, respectively, but the rump height of indigenous sheep in Legambo was 60.67±0.38. The body weight of indigenous sheep in this study was similar to the observation by Bimerow *et al.* (2011) who reported 25.8±0.26 kg for Farta sheep. Still, it was lower than that of Taye *et al.* (2016) who reported 31.64±0.43 kg for Doyogena sheep, and Michael *et al.* (2016), who reported 29.0±0.2 for East Gojam (Gozamen, Sinan and Huleteju) sheep.

For indigenous sheep, sex of the sheep had significant (p <0.01) effect on body condition score, body weight, chest girth, wither height, tail length, tail circumference, rump height and horn length. Whereas body length and ear length of indigenous sheep were not affected (p >0.05) by sex of the sheep. This finding was in agreement with Getachew *et al.* (2009). who reported a significant association of sex with body condition score, body weight, chest girth, wither height, tail length, tail circumference and rump height in Menz and Afar sheep. Similar to our finding body length and ear length were not affected by sex of the sheep in the same study. Gebreyowhens and Tesfay (2016) reported significant (p <0.05) effects of sex on body weight and other linear body measurements except ear length from Atsbiwonberta district of Tigray Region. Mengistie *et al.* (2010) obtained a slightly different result in which they reported a significant effect of sex on body weight, heart girth and height at wither, but also a significant association of body length with sex - different from our study, in Washera sheep. In contrast to our result Amelmal (2011) reported no significant association of sex of sheep with body weight and other linear measurements (p >0.05), except BCS. Haylom *et al.* (2014) also reported that sex had no significant (p >0.05) effect on body weight, chest girth, body length and height at wither in highland sheep in Atsbiwonberta.

In this study body weight and all other linear body measurements of indigenous sheep were significantly (p <0.05) affected by age of the sheep. Except BCS, body weight and all linear body measurements increased as the age increased from the youngest (0PPI) to the oldest (≥ 2PPI). The result of the current study was in line with a previous report by Gebreyowhens and Tesfay (2016), which stated that the average values of live body weight, chest girth, body length, and height at wither significantly (p<0.05) increased as the age of animals advanced, in a highland sheep population in Tigray Region. As the age of the male and female sheep increased, their body size also increased. At the same age, males were heavier than female sheep. Both sex and age have a synergistic effect on body size of the animal (Gebreyowhens and Tesfay, 2016). The interaction of sex and age was significant (p <0.05) for BCS, body weight, chest girth, wither height, tail length, tail circumference, rump height, and horn length but not for body length and ear length. The significant effect of interaction between sex and age on body measurements observed in the current study was in agreement with reports of Getachew *et al.* (2009) for Menz and Afar sheep, Mohammed *et al.* (2014) for Habru and Gubalafto districts, and Gebreyowhens and Tesfay (2016) for Atsbiwonberta district. Body weight, chest girth, height at wither, and height at rump were significantly affected p<0.05), while body length and ear length were not significantly affected (p >0.05) by sex by age interaction. However, in contradiction to our finding, Michael *et al*. (2016) reported significant effect of age by sex interaction only for body weight. In all age groups, indigenous male sheep were heavier (p <0.05) than female sheep.

Multivariate analysis

According to Peter *et al*. (2012), the stepwise discriminant analysis of RH and WH in this study is significant. At the 5% level of significance, the relative relevance of the found morphometric features in differentiating the three populations of sheep was evaluated. Wilk's Lambda decreased to 0.33 and 0.24 with a significant difference between the three location sheep populations (F = 2.20; p<0.05) and (F = 3.71; p <0.05), respectively, indicating the proportion of total variability not explained by the discriminator variables between populations when the most discriminating traits of both females (RH, WH, BW, TC, BCS, EL, CG, and BL) and males (RH, HL, BW, WH, and BL) respectively. This suggests that differences across populations, as opposed to variance within populations, accounted for the majority of the variability in the discriminator variables (67% for females and 76% for males).

As important discriminating variables were added chronologically, the partial R2 static decreased, indicating the proportion of each variable's variability that was explained by population differences. This pattern was similar to Wilk's Lambda value. The results indicate that RH had the strongest discriminating power in females, with BW, TC, BCS, EL, CG, and BL following in descending order, as indicated by the corresponding partial R2 and F-values. Meanwhile, RH exhibited the greatest discriminating power in males, followed by HL, BW, WH, and BL. This suggests that compared to females, who needed the measurement of eight traits, males needed slightly fewer trait measures to distinguish between the sheep populations in the three locations. When multivariate normality was checked, multi-attributes did not exhibit a combined multivariate normal distribution for the populations, according to the estimated significant (p <.0.05) multivariate skewness and kurtosis values. By calculating the likelihood of misclassification or error rates, one can assess how well a discriminant function performs in classifying new observations.

The three locations' combined average error count estimate for sheep was 30%, accounting for 44%, 33%, and 14% of the population of Wogide, Borena, and Legambo sheep, respectively. This indicates that 70% of sheep across all populations were identified in their original population with accuracy. The population of sheep classed as Legambo (85.83%) was found to be part of its source population, with Wogide (56.30%) and Borena (66.67%) following suit. The percentage of sheep that were incorrectly classified as Wogide was approximately 33.33%, whereas the percentage of sheep that were incorrectly classed as Borena was

28.00%. There was a misclassification of approximately 5.00% and 9.17% of the Legambo sheep population into the Wogide and Borena sheep populations. Ten point four percent of Wogide sheep and 5.3% of Borena animals were incorrectly assigned to the Legambo area. The highest misclassification of Wogide (33.3% in the Borena location) and Borena (28.0% in the Wogide location) may be related to the close proximity of their habitats, while the lowest misclassification of the Legambo sheep population may indicate greater homogeneity within the population.

To determine the Mahalanobis distances between the sample populations, the canonical discriminant analysis was used. The study was carried out via a step-wise discriminant analysis approach to find the most significant discriminant variables for females (RH, WH, BW, TC, BCS, EL, CG, and BL) and males (RH, HL, BW, WH, and BL). The squared Mahalanobis distance between the places, however, was determined to be greater. The sheep populations from the Wogide and Borena locations were minimally differentiated (0.83), whereas the greatest distance was seen between the Wogide and Legambo locations (6.84) and between the Borena and Legambo locations (6.76). Any conservation and development plan should begin with evaluating the level of diversity in the population since genetic variation is essential for populations to respond to artificial selection and adapt to changing environments (Toro *et al.,* 2011).

Conclusions

Sheep in the study locations were categorized as short fat-tailed (100%), with a primarily upward-curving tail tip. Around 96.79% of sheep had long and coarse hair, while the remaining sheep had short smooth hair. Three coat color types were noted in the research areas: red, dark grey, and plain white. In all linear body dimensions and body weight, there was a difference in these places. Genetic variations and environmental factors could be attributed to this.

The most significant distinguishing characteristics between females were found to be eight (RH, WH, BW, TC, BCS, EL, CG, and BL) in the stepwise discriminant analysis approach, and five (RH, HL, BW, WH, and BL) in the case of males. While the misclassification of Wogide and Borena sheep populations may be higher because of their close proximity to one another, the lowest misclassification of the Legambo sheep population may indicate greater homogeneity within the population. The sheep populations from the Wogide and

Borena locations were not well differentiated, whereas the greatest distance was identified between the Wogide and Legambo locations and between the Borena and Legambo locations.

Sheep has the ability to boost smallholder farmers' economies and standard of living in the study areas. It was discovered that the indigenous sheep populations of Wogide and Borena were bigger. Thus, before diluting the adapted and reasonably productive genotype, it would be imperative to conserve and enhance the native sheep in Wogide and Borena in their natural habitat. More genetic analysis research is recommended to assess variations and similarities of sheep and to identify potential of the genetic resources.

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