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Phenotypic characterization of sheep populations in Tahtay Maichew district, Northern Ethiopia

Abebe Hailu [a], **Amine Mustefa** [*,a], **Tesfalem Aseged** [a], **Abraham Assefa** [a], **Seble Sinkie** [a] and **Semere Tsewene** [b]

[a] *Ethiopian Biodiversity Institute, P.O.Box 30726, Addis Ababa, Ethiopia*
[b] *Ethiopian Biodiversity Institute, Mekelle Biodiversity Center, P.O.Box 30726, Mekelle, Ethiopia*

Abstract: Eighteen quantitative measurements and fourteen qualitative characteristics taken from 306 adult sheep (57 rams and 249 ewes) were used to phenotypically characterize sheep populations of Tahtay Maichew district, Ethiopia. Most traits showed significant variation by agro-ecological zone, sex and age groups with higher values generally recorded for rams as compared to ewes. Middle age group animals displayed highest values for several traits, reflecting the optimal production age. Agro-ecological zone affected ewes more than rams. The highland sheep had shortest height at withers, widest shoulder points and longest hair, indicative of adaptation to their environment. Qualitative characteristics of the studied sheep populations such as tail shape, plain coat color pattern, unpigmented skin, hairy fiber and the absence of horn, toggle, ruff and beard suggest that they constitute a previously undescribed sheep breed. Tan coat color differentiated high and midland sheep from lowland sheep where white and brown colors were dominant. Canon bone length, height at withers and tail length were the three most important morphometric variables used in discriminating the sheep populations. On average 66% of the animals could be classified into their respective agro-ecological zone. Our data suggest that highland sheep populations are distantly related to lowland sheep, while midland sheep are more closely related to lowland sheep. It can be concluded that breeding programs specific to each agro-ecological zone need to be designed for sustainable utilization and conservation of the studied sheep populations. Furthermore, molecular based studies might allow further characterization of Ethiopian sheep breeds.

Keywords: Indigenous breed, Sheep genetic resources, Morphological characterization, Qualitative traits, Tigray region, Ethiopia

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Introduction

The Ethiopian livestock sector, which is mainly dominated by indigenous animal genetic resources, contributes significantly to the economy and food security of the country (Central Statistical Agency, 2018), providing livelihood for 37-87% of the country's population (Central Statistical Agency, 2005). This sector contributes 15 — 17% and 35 — 49% of the total and agricultural Gross Domestic Product, respectively (Michael *et al*, 2016). Within the livestock sector, small ruminants, especially sheep, provide a sustainable option for smallholder low input-output production systems. Indigenous sheep genetic resources play a major role in developing countries like Ethiopia, as are better adapted to environments which are harsh, marginal and degraded, have low body weight and excellent grazing skills (Misra and Singh, 2002; Degen, 2007). The indigenous sheep genetic resources account for 99.81% of the total sheep population in Ethiopia (Central Statistical Agency, 2018).

Conducting phenotypic characterization is a prerequisite for sustainable utilization, conservation and improvement of a breed through designing appropriate sheep breeding programs (FAO, 2012). This will fur-

*Corresponding author: Amine Mustefa (aminemustefa32@gmail.com)

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ther maximize sustainable food security while minimizing pressure on the environment. Ethiopia, one of the major gateways for domestic sheep to Africa (Devendra and Mcleroy, 1982), is believed to have the largest livestock population in Africa with 31.3 million sheep (Central Statistical Agency, 2018) categorized into 14 traditionally recognized and phenotypically distinct sheep populations (9 breeds within 6 breed groups) (Gizaw *et al*, 2008; EBI, 2016). The 9 sheep breeds of Ethiopia are Simien, Short fat tailed, Washera, Gumz, Horro, Arsi, Bonga, Afar and Black Head Somali (BHS) (Gizaw *et al*, 2008). In literature, sheep populations of the current study area were generally classified as Sekota traditional population and further categorized under the Short fat tailed breed (Gizaw *et al*, 2008). However, samples were not taken from nearby areas of the current study areas.

Sekota sheep populations were characterized as short fat tail turned-up at end and fused with main part. The population is medium-sized, predominantly brown or white coat color, few blacks with brown belly. The white animals have finer hair or wooly udder-coat, semi-pendulous or rudimentary ears in Wag Himra and Tigray while predominantly rudimentary in Tekeze valley. Sekota sheep population were reared by Agew, Tigray and Amhara communities (Gizaw *et al*, 2008).

However, due to the country's high ecological and production system variations, some of the breeds were re-characterized in more recent studies, including Simien sheep (Melaku *et al*, 2019), Short fat tailed sheep (Hayelom *et al*, 2014; Bimerow *et al*, 2011; Getachew *et al*, 2009), Washera sheep (Mengistie *et al*, 2010), Arsi sheep (Worku, 2018); Afar sheep (Getachew *et al*, 2009). In addition to these studies, some work was done in the Tigray region on Abergelle sheep (Tajebe *et al*, 2011) and Tigray Highland sheep (Gebreyowhens and Tesfay, 2016).

Despite the efforts made to characterize the Ethiopian indigenous sheep genetic resources as mentioned above, they have not yet been exhaustive in covering all regions of the country in general and the Tigray region in particular. They also focused on only a few specifically well-known sheep populations. As a consequence, a high sheep diversity remains unstudied, along with the associated diversified ecology, production systems and ethnic groups. Therefore, there is an urgent need for continued characterization and identification to understand the relationships within and among breeds. Thus, the present study was initiated to cover these gaps and phenotypically describe the indigenous sheep populations of Tahtay Maichew district, Central Tigray zone, Ethiopia.

Materials and methods

Study Areas

The study was carried out in the Tahtay Maichew district, which is located in the central zone of Tigray National Regional State (Figure 1). The district covers a total area of 18,618 km^2 with estimated livestock population size of 247,907, consisting 75,707 cattle, 55,517 goats, 110 mules, 6,716 donkeys, 25,195 sheep and 84,102 poultry (Atsbeha *et al*, 2015). The studied areas were categorized as highland, midland and lowland based on the climatic factors in Table 1.

Table 1. Climatic factors and sheep population size of the threeagro-ecological zones in the Tahtay Maichew district of Tigray region, Ethiopia.

Variables	Highland	Midland	Lowland
Altitude in meters	> 2500	1500 – 2500	< 1500
Temperature in °C (mean)	9.9	19.9	30.3
Annual rainfall in mm (mean)	600 – 700	500 – 600	400 – 500
Sheep population size	11,816	8,903	4,476

Site selection and data collection

Available background information on the existence of unstudied sheep populations adapted to different agro-ecological zones was captured through short pilot survey and focus group discussions with livestock experts and keepers. Two sites (kebeles) were sampled randomly from each agro-ecological zone (see Table 1). Quantitative and qualitative data were recorded from a total of 306 adult sheep (57 rams and 249 ewes) based on data collection procedures outlined in FAO guidelines (FAO, 2012). Studied animals were carefully handled by trained personnel. Quantitative measurements were taken early in the morning of the day before feeding and watering when the animals were calm and standing in an upright position on flat ground.

Eighteen quantitative measurements were collected: body length (cm), body weight (kg), heart girth (cm), height at withers (cm), chest depth (cm), shoulder point width (cm), subs height (cm) rump length (cm), rump width (cm), tail length (cm), tail width (cm), head length (cm), head width (cm), shin circumference (cm), horn length (cm), hair length (cm), canon bone length (cm), ear length (cm), testis circumference (cm). Fourteen qualitative characteristics were also collected: coat color pattern, coat color, skin color, fiber type, ear orientation, head profile, back profile, rump profile, tail type, tail shape and presence of toggle, horn, beard and ruff were recorded.

Statistical Analysis

Data were entered and managed using Microsoft Excel© worksheet. Detection of outliers and testing the normality of the quantitative measurements data was performed using the UNIVARIATE procedure of Statistical Analysis Software (SAS) 9.0 (SAS Institute, 2002). Analysis of data on quantitative measurements and qualitative characteristics was carried out using the General Linear Model (GLM) procedure and the frequency (FREQ) procedure of SAS 9.0 software,

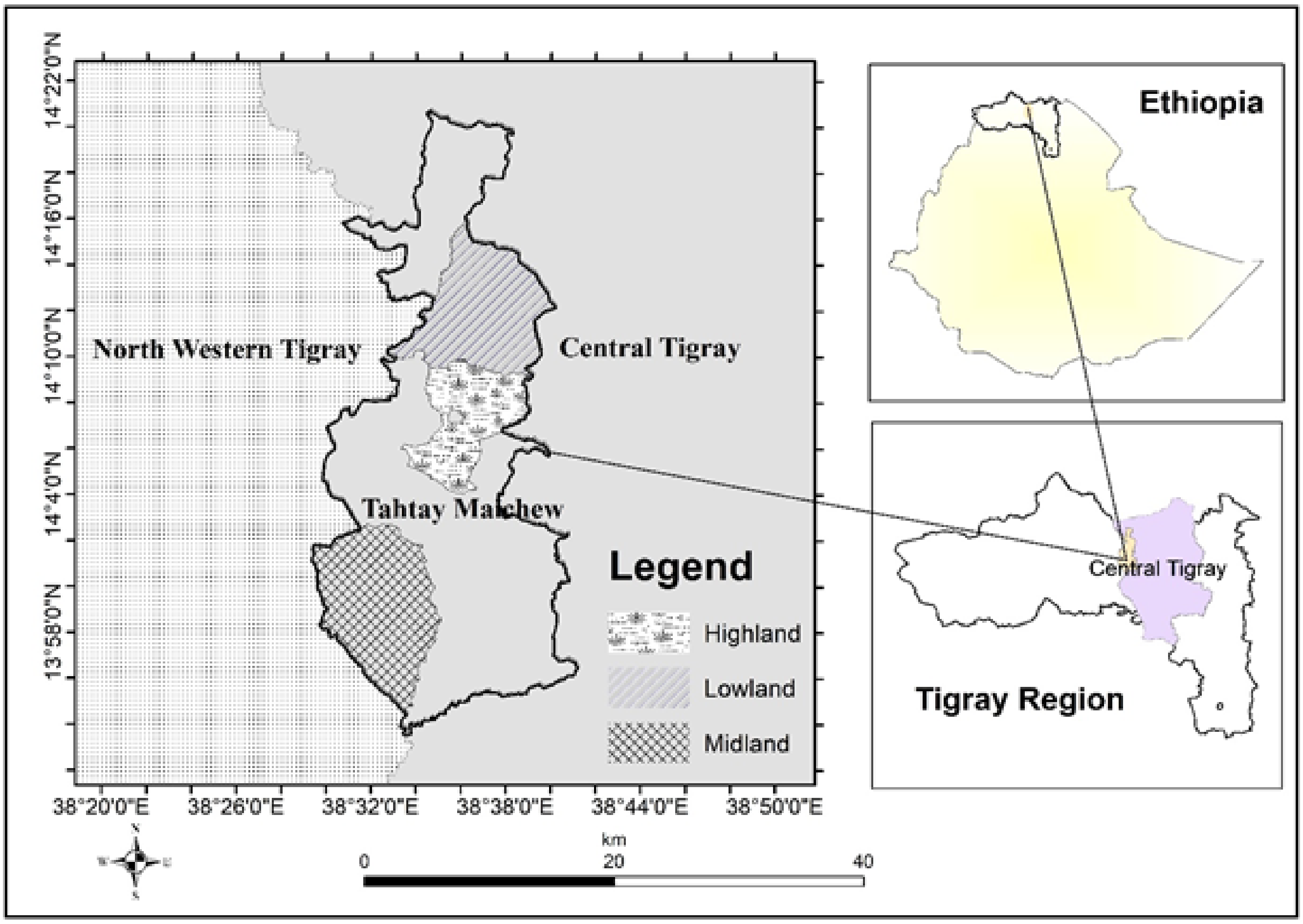

Figure 1. Map of the studied areas.

respectively. Linear measurements Least Square Means (LSM) were separated using the adjusted Tukey-Kramer test (SAS Institute, 2002). Quantitative and qualitative data were analyzed using the following model:$Y_{ijk} = \mu + A_i + B_j + C_k + e_{ijk}$ where Y_{ijk} is an observation, μ is the overall mean, A_i is the fixed effect of environment, B_j is the fixed effect of the sex, C_k is the fixed effect of age group and e_{ijk} is the random error attributed to the nth observation. Environment, sex and age group were fitted as class variables throughout the analysis, while sex effect was removed from the class variables when the analysis was done separately for each sex.

Multivariate analysis was performed on quantitative measurements. Stepwise discriminant function analysis (STEPDISC) with forward selection procedure was used to find out the quantitative variables that better discriminate populations from different environment. Percentage assignment of observations to environment and probabilities of misclassifications were evaluated by discriminant function analysis (DISCRIM). Canonical discriminant function analysis (CANDISC) was also performed to find out linear combination of quantitative variables that provide maximal separations between environments. The scored canonical variables were used to plot pairs of canonical variables to get visual interpretation of environmental differences. Pairwise squared Mahalanobis distances between environments were computed as: $D^2\,(i|j) = (x_i - x_j)^{'} cov^{-1}\ (x_i - x_j)$. Where $D^2\,(i|j)$ is the distances between environments zones i and j, cov^{-1} is the inverse of the covariance matrix of measured variables, x_i and x_j are the means of variables in the i^{th} and j^{th} populations.

Results

Quantitative measurements

Level of significance (P-values) outputs of the class variables for both the overall analysis and separately for each sex are presented in Table 2. Overall, most of the studied traits were significantly affected by agro-ecological zone, age and sexual differences. Effect of agro-ecological zone on some quantitative traits (heart girth, height at withers, shoulder point width, rump length, tail length, head length, hair length, canon bone length, and ear length) was more significant on ewes than rams.

The overall mean with the respective standard error and deviation, and the effect of agro-ecological zone, sex and age on the quantitative measurements are presented in Tables 3, 4 and 5. The highland sheep population had the shortest height at withers, widest shoulder points and longest hair, while midland sheep population

Table 2. Level of significance for the overall analysis and separately for both sexes

Traits	Overall			Rams		Ewes	
	Agro-eco zone	Age	Sex	Agro-eco zone	Age	Agro-eco zone	Age
BL (cm)	0.2688	<0.0001	0.3394	0.3930	0.0028	0.3873	0.0004
BW (kg)	0.5309	<0.0001	0.9515	0.3384	0.0061	0.6135	<0.0001
HG (cm)	0.0330	<0.0001	0.6983	0.0772	0.0002	0.0399	<0.0001
HAW (cm)	0.0005	0.0250	0.0617	0.0562	0.0009	0.0075	0.5451
CD (cm)	0.0486	0.0013	0.0267	0.1216	0.0120	0.2068	0.0397
SPW (cm)	0.0012	<0.0001	0.0017	0.8511	0.0008	<0.0001	0.0078
SH (cm)	0.5553	0.5924	0.2194	0.1241	0.9660	0.8881	0.7606
RL (cm)	<0.0001	0.2364	0.2377	0.8307	0.8157	<0.0001	0.1604
RW (cm)	0.7008	0.0028	0.4727	0.2884	0.0001	0.3402	0.0504
TL (cm)	0.0003	0.9584	0.0040	0.1598	0.2868	0.0007	0.2635
TW (cm)	0.3219	0.3538	<0.0001	0.5269	0.0064	0.2726	0.8968
HL (cm)	<0.0001	0.0002	0.0410	0.2124	0.0213	<0.0001	0.0062
HW (cm)	0.0283	0.0092	<0.0001	0.2161	0.9169	0.0597	0.0122
SC (cm)	0.4564	0.0003	<0.0001	0.5994	0.0001	0.6909	0.2794
HRL (cm)	<0.0001	0.0076	0.0007	0.1643	0.3147	<0.0001	0.0123
CBL (cm)	<0.0001	0.0377	0.2666	0.6187	0.0349	<0.0001	0.1417
EL (cm)	<0.0001	0.0365	0.6856	0.5261	0.4147	0.0002	0.0153
TC (cm)	-	-	-	0.0253	0.0114	-	-

BL = body length, BW = body weight, HG = heart girth, HAW = height at withers, CD = chest depth, SPW = shoulder point width, SH = subs height, RL =rump length, RW = rump width, TL = tail length, TW = tail width, HL =head length, HW = head width, SC = shin circumference, HRL = hair length, CBL = canon bone length, EL = ear length, TC = testis circumference.

possessed the shortest tail and ear. Almost half of the measured traits were affected by sex of the animals showing higher values for males.

Most of the overall agro-ecological zone differences were due to the differences within the ewes. However, testis circumference, the only trait among the rams which is affected by agro-ecological zone, increases significantly as we shift from highland to lowland.

The majority of the quantitative measurements were significantly affected by the age of the animals (Figures 2, 3 and 4). Accordingly, values of some traits (body weight, chest depth, shoulder point width, rump width, testis circumference, body length, heart girth, and height at withers) gradually increased towards the optimum age of three years and then decreased towards the oldest age (5 years; Figures 2 and 3). However, this was not true in some traits (head length, head width, shin circumference, hair length, canon bone length, and ear length; Figure 4). On the other hand, age did not affect subs height, rump length, rump width, tail length, and tail width.

Qualitative characteristics

The outputs of the chi-squared tests, if the qualitative characteristics of the sheep populations from the three agro-ecological zones differ, are presented in Table 5. Accordingly, ear orientation, back profile, head profile, rump profile and coat color of the three agro-ecological zones were significantly different (Table 5). On the other hand, the coat color pattern, fiber type, skin color, tail type, tail shape and presence of toggle, horn, beard

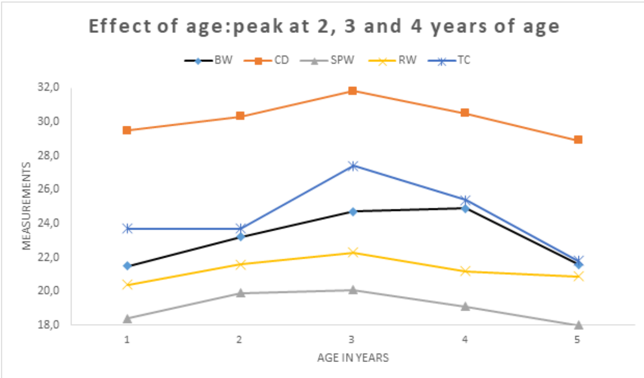

Figure 2. Effect of age on body weight(BW), chest depth (CD), shoulder point width (SPW), rump width (RW), and testis circumference (TC).

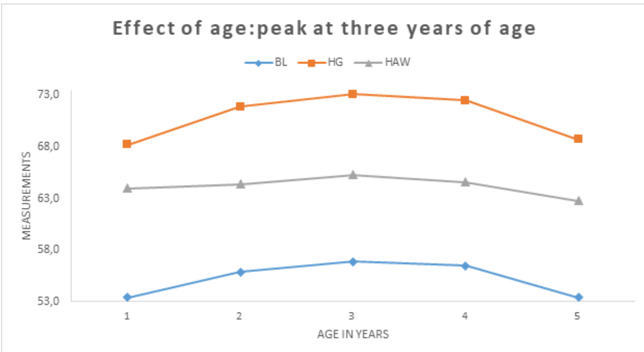

Figure 3. Effect of age on body length (BL), heart girth (HG), and height at withers (HAW)

Table 3. Overall mean ($\bar{X}$), standard error (SE), standard deviation (SD) and pairwise mean comparison (least square means and standard errors) for the effect of agro-ecological zone and sex. Means within a column bearing different superscripts are significantly different; a is given to the highest value.

Traits	Overall		Agro-ecological zone			Sex	
	$\bar{X}$±SE	SD	Highland	Midland	Lowland	Rams	Ewes
N	306		102	102	102	57	249
BL (cm)	55.2±0.2	4.0	54.7±0.5	55.4±0.4	55.5±0.4	55.6±0.6	54.9±0.3
BW (kg)	23.5±0.2	3.4	22.9±0.4	23.4±0.3	23.3±0.4	23.2±0.5	23.2±0.2
HG (cm)	71.0±0.3	4.9	71.8±0.5^{a}	70.1±0.5^{b}	70.7±0.5^{ab}	71.0±0.7	70.7±0.3
HAW (cm)	63.9±0.2	3.2	63.2±0.4^{b}	64.5±0.3^{a}	64.9±0.4^{a}	64.8±0.5	63.7±0.2
CD (cm)	29.8±0.2	3.1	30.0±0.4	30.0±0.3	30.8±0.3	30.9±0.5	29.6±0.2
SPW (cm)	18.7±0.1	2.3	19.7±0.3^{a}	18.6±0.3^{b}	19.0±0.3^{b}	19.8±0.3	18.4±0.2
SH (cm)	32.9±0.1	2.5	32.8±0.3	33.1±0.3	33.1±0.3	33.3±0.4	32.7±0.2
RL (cm)	14.9±0.1	2.2	15.6±0.3^{a}	15.2±0.2^{a}	14.1±0.2^{b}	15.2±0.3	14.7±0.2
RW (cm)	21.3±0.1	2.3	21.2±0.3	21.4±0.2	21.2±0.3	21.1±0.4	21.4±0.2
TL (cm)	16.8±0.2	3.1	17.5±0.4^{a}	16.3±0.3^{b}	18.0±0.3^{a}	18.1±0.5	16.4±0.2
TW (cm)	16.8±0.2	3.0	18.0±0.3	17.5±0.3	17.5±0.3	19.0±0.5	16.3±0.2
HL (cm)	13.9±0.1	1.5	14.4±0.2^{a}	14.0±0.2^{a}	13.4±0.2^{b}	14.2±0.2	13.6±0.1
HW (cm)	10.2±0.1	1.3	10.4±0.1^{b}	10.8±0.1^{a}	10.4±0.1^{b}	11.1±0.2	9.9±0.1
SC (cm)	6.8±0.1	0.8	7.0±0.1	7.1±0.1	6.9±0.1	7.3±0.1	6.6±0.1
HRL (cm)	4.5±0.1	1.3	5.2±0.1^{a}	4.6±0.1^{b}	4.5±0.1^{b}	5.2±0.2	4.4±0.1
CBL (cm)	12.3±0.1	1.2	12.7±0.1^{a}	12.5±0.1^{a}	11.8±0.1^{b}	12.5±0.2	12.2±0.1
EL (cm)	7.6±0.2	3.0	7.8±0.4^{a}	6.4±0.3^{b}	8.4±0.4^{a}	7.7±0.5	7.4±0.2

N = number of observations, BL = body length, BW = body weight, HG = heart girth, HAW = height at withers, CD = chest depth, SPW = shoulder point width, SH = subs height, RL =rump length, RW = rump width, TL = tail length, TW = tail width, HL =head length, HW = head width, SC = shin circumference, HRL = hair length, CBL = canon bone length, EL = ear length.

Table 4. Pairwise mean comparison (least square means and standard errors) for the effect of agro-ecological zonewithin each sex. Means within a column bearing different superscripts are significantly different; a is given to the highest value.

Traits	Rams			Ewes		
	Highland	Midland	Lowland	Highland	Midland	Lowland
N	14	26	17	88	76	85
BL (cm)	56.3±1.3	56.1±0.9	57.6±1.0	54.7±0.5	55.5±0.5	55.3±0.5
BW (kg)	23.2±1.1	23.7±0.7	24.8±0.8	23.3±0.4	23.7±0.4	23.3±0.4
HG (cm)	73.2±1.5	70.6±1.0	73.3±1.2	72.2±0.6^{a}	70.6±0.6^{b}	70.6±0.6^{b}
HAW (cm)	65.0±1.1	65.7±0.7	67.6±0.8	63.1±0.4^{b}	64.4±0.4^{a}	64.4±0.4^{a}
CD (cm)	30.2±1.2	30.8±0.8	32.5±0.9	29.7±0.3	29.4±0.4	30.2±0.4
SPW (cm)	20.0±0.9	19.9±0.6	20.3±0.7	19.6±0.2^{a}	18.1±0.3^{b}	18.5±0.2^{b}
SH (cm)	32.0±1.0	34.0±0.6	33.3±0.7	32.7±0.3	32.7±0.3	32.8±0.3
RL (cm)	15.3±0.8	14.8±0.5	14.9±0.6	15.5±0.3^{a}	15.2±0.3^{a}	13.7±0.3^{b}
RW (cm)	22.6±0.8	21.4±0.5	22.1±0.6	21.6±0.3	21.9±0.3	21.4±0.3
TL (cm)	19.2±1.2	17.2±0.8	18.7±0.9	16.9±0.3^{a}	15.7±0.4^{b}	17.4±0.3^{a}
TW (cm)	19.9±1.1	18.7±0.7	19.3±0.8	16.9±0.3	16.4±0.4	16.3±0.3
HL (cm)	15.2±0.6	14.6±0.4	14.1±0.4	14.2±0.2^{a}	13.8±0.2^{a}	13.2±0.2^{b}
HW (cm)	10.4±0.6	11.4±0.4	11.2±0.5	9.8±0.1	10.2±0.1	9.7±0.1
SC (cm)	7.4±0.3	7.7±0.2	7.5±0.3	6.7±0.1	6.7±0.1	6.6±0.1
HRL (cm)	4.9±0.5	5.4±0.3	4.5±0.4	5.0±0.1^{a}	4.1±0.2^{b}	4.2±0.1^{b}
CBL (cm)	12.6±0.4	12.9±0.2	12.6±0.3	12.8±0.1^{a}	12.4±0.1^{a}	11.7±0.1^{b}
EL (cm)	7.6±1.1	7.2±0.7	8.3±0.8	7.5±0.4^{a}	6.1±0.4^{b}	8.2±0.4^{a}
TC (cm)	23.2±1.1^{b}	24.0±0.7^{ab}	26.1±0.8^{a}	-	-	-

N = number of observations, BL = body length, BW = body weight, HG = heart girth, HAW = height at withers, CD = chest depth, SPW = shoulder point width, SH = subs height, RL = rump length, RW = rump width, TL = tail length, TW = tail width, HL = head length, HW = head width, SC = shin circumference, HRL = hair length, CBL = canon bone length, EL = ear length, TC = testis circumference.

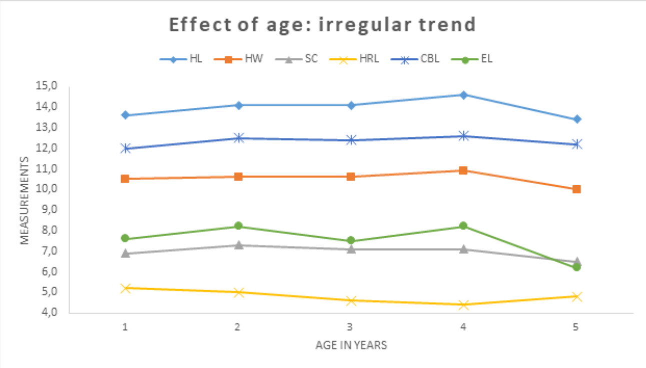

Figure 4. Effect of age on head length(HL), head width (HW), shin circumference (SC), hair length (HRL), canon bone length (CBL), and ear length (EL)

and ruff were not significantly different among the studied agro-ecological zones. Accordingly, the sheep populations can be characterized as hair type sheep with plain coat color pattern. Additionally, all of the studied sheep populations possess cylindrical thin tail with turned up at end, and straight head profile. The results also revealed that almost none of the sheep sampled have pigmented skin, horns, toggle, ruff and beard. Tan coat color was dominantly observed in the high and midland agro-ecological zones while white and brown colors were dominant in the lowland sheep (Figures 5, 6 and 7).

Multivariate analysis for discrimination of sheep populations

According to stepwise discriminant function analysis, canon bone length, height at withers and tail length were the three most important morphometric variables used in discriminating the sheep populations from different agro-ecological zones (Table 6). Chest depth, subs height, body length, and tail width were found not to be useful variables due to their lowest discriminatory power (Table 6).

The probabilities of all main multivariate tests over the canonical structures were significant (Table 7).

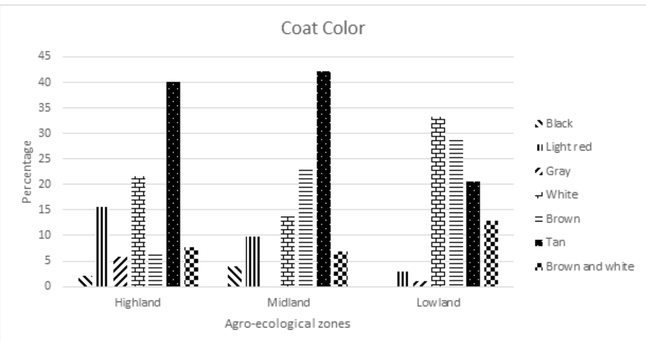

Figure 5. Coat color of sheep populations from different agro-ecological zones; significant ($p<0.0001$) effect of agro-ecological zones was observed over the coat color of the studied sheep populations.

Table 5. Percentages and their respective chi-squared probabilities of some qualitative characteristics of the sheep populations from different agro-ecological zones. χ^2values in bold are statistically significant.

Qualitative traits	Agro-ecological zones			
	Highland	Midland	Lowland	χ^2
Coat color pattern				0.1445
Plain	77.5	85.3	82.4	
Patchy	17.6	12.7	17.6	
Spotted	4.9	2.0	NR	
Fiber type				0.8211
Hairy	85.3	86.3	88.2	
Wooly	14.7	13.7	11.8	
Ear orientation				**0.0127**
Erect	1.0	1.0	4.9	
Semi-pendulous	48.0	34.3	37.2	
Pendulous	25.5	16.7	21.6	
Carried horizontal	25.5	48.0	36.3	
Head profile				**0.0100**
Straight	71.6	65.7	85.3	
Concave	12.7	11.8	8.8	
Convex	15.7	22.5	5.9	
Back profile				**0.0002**
Straight	70.5	40.2	62.8	
Slopes up towards the rump	25.5	56.9	34.3	
Slopes down from withers	2.0	2.9	2.9	
Curved	2.0	0	0	
Rump profile				**<0.0001**
Flat	27.5	59.8	50.0	
Sloping	72.5	40.2	48.0	
Roofy	0	0	2.0	
Toggle				0.0987
Present	3.9	11.8	10.8	
Absent	96.1	88.2	89.2	

Canonical correlation coefficients of the quantitative variables and class means outputs from the two canonical structures are shown in Table 8. The first canonical structure (Can 1) explains the majority (69%) of the variability with eigenvalue of 0.48. The first canonical correlation (57%) was the greatest multiple correlation with the classes that was achieved by using the linear combination of the quantitative variables. The results revealed that Can 1 separates the sheep populations (class means) from different agro-ecological zones.

Results of a discriminant function analysis (Table 9) shows the classification of data into a known agro-ecological zone. Accordingly, an average of 66% of the sampled animals were classified into their respective

Table 6. Summary of the stepwise discriminant function analysis; ascending order of traits used in discriminating the sheep populations from different agro-ecological zones.

Step	Variables entered	Partial R-squared	F value	Pr > F	Wilk's Lambda	Pr < Lambda
1	Canon bone length	0.1237	21.39	<0.0001	0.8763	<0.0001
2	Height at withers	0.0564	9.02	0.0002	0.8269	<0.0001
3	Tail length	0.0557	8.87	0.0002	0.7809	<0.0001
4	Rump length	0.0554	8.79	0.0002	0.7376	<0.0001
5	Head width	0.0529	8.36	0.0003	0.6986	<0.0001
6	Hair length	0.0460	7.18	0.0009	0.6664	<0.0001
7	Head length	0.0525	8.23	0.0003	0.6315	<0.0001
8	Shoulder point width	0.0308	4.70	0.0098	0.6120	<0.0001
9	Shin circumference	0.0258	3.91	0.0210	0.5962	<0.0001
10	Heart girth	0.0172	2.58	0.0777	0.5860	<0.0001
11	Body weight	0.0268	4.03	0.0188	0.5703	<0.0001
12	Rump width	0.0147	2.18	0.1154	0.5619	<0.0001
-	Chest depth	0.0073	1.07	0.3432	-	-
-	Subs height	0.0013	0.18	0.8314	-	-
-	Body length	0.0010	0.15	0.8595	-	-
-	Tail width	0.0008	0.12	0.8876	-	-

agro-ecological zone. The overall error rate was 34%, while higher error rates were obtained from the classification of midland sheep populations.

Pairwise squared distances between agro-ecological zones are shown in Table 10. All distances were significant. Highland sheep populations are distantly related to the lowland sheep. On the other hand, midland sheep relates more towards lowland sheep than highland sheep.

Table 7. Multivariate statistics and F approximates

Statistic	Value	F Value	Num DF	Den DF	Pr > F
Wilks' Lambda	0.5559	6.14	32	576	<0.0001
Pillai's Trace	0.5015	6.04	32	578	<0.0001
Hotelling-Lawley Trace	0.6957	6.24	32	510.82	<0.0001
Roy's Greatest Root	0.4811	8.69	16	289	<0.0001

Table 8. Eigen values, canonical correlations and class means

	Can 1	Can 2
Multivariate Statistics		
Canonical correlation	**0.5699**	0.4203
Eigenvalue	**0.4811**	0.2146
Proportion	**0.6916**	0.3084
Class (agro-ecological zones)		
Highland	**0.9139**	-0.2290
Lowland	**-0.7539**	-0.4141
Midland	**-0.1600**	0.6430

Discussion

Along with the most observable qualitative traits, quantitative measurements produce reliable information in characterization and differentiation of sheep populations. In our current study, more traits showed significant differences among ewes than among rams in different agro-ecological zones. This might be due to either the larger sample size taken for ewe populations or due to the similarity of rams over the studied agro-ecological zones, which could be attributed to common markets

Table 9. Number and percent of observations classified into agro-ecological zones.

From	Highland	Lowland	Midland	Total
Highland	70 (68.6)	20 (19.6)	12 (11.8)	102 (100)
Lowland	12 (11.8)	71 (69.6)	19 (18.6)	102 (100)
Midland	19 (18.6)	23 (22.6)	60 (58.8)	102 (100)
Total	101 (33.0)	114 (37.3)	91 (29.7)	306 (100)
Error rate	0.31	0.30	0.41	0.34
Priors	0.33	0.33	0.33	

Table 10. Squared Mahalanobis distance between agro-ecological zones; output of the multivariate analysis calculated using the quantitative measurements

From	Highland	Lowland	Midland
Highland	0		
Lowland	2.82***	0	
Midland	1.91***	1.47***	0

*** shows the significance of the distance calculations at p<0.0001.

Figure 6. Lowland sheep flock in Tahtay Maichew district.

where farmers select and purchase rams for sire purposes.

Most of the studied traits were affected by agro-ecological zone differences, which might be due to the differences in physiological adaptation mechanism of sheep types to different environments, management, availability of different feed and nutrition and/or the variations being caused by genetic factors. For example, the majority of lowland sheep possess higher values for height at withers, testis circumference and short hair which might help them to adapt to a hot environment. These results are in line with the results of Getachew *et al* (2009) and Gizaw *et al* (2008) for Menz and Afar sheep who reported that such measurements of the lowland Afar sheep were higher than the highland Menz sheep populations.

Most of the body measurements were higher for rams than ewes, which might be attributed to enhanced muscle mass and skeletal development in males due to testosterone hormone secretions (Baneh and Hafezian, 2009). These results follow Rensch's rule where the males of a particular species are usually heavier than the females (Rensch, 1950). Size differences may be ascribed to the differences in the endocrine system of the two sexes; estrogen hormone was shown to have a limited effect on growth in females (Baneh and Hafezian, 2009). These results are in agreement with Mustefa *et al* (2019) and Getachew *et al* (2009) who reported that males were higher than the females in most growth traits in goats and sheep respectively.

In agreement with the results of the current study, most scholars report differences in traits between the sexes with rams being dominant over ewes (Rensch, 1950; Baneh and Hafezian, 2009; Mustefa *et al*, 2019; Getachew *et al*, 2009). However, differences due to sex was not observed in Tigray Highland sheep populations (Hayelom *et al*, 2014). In contrast to this, Hayelom *et al* (2014) report the dominance of ewes over the rams on most of the linear body measurements of Elle sheep populations. In a different study, no significant differences were observed among body weight of Simien sheep ewes and rams (Melaku *et al*, 2019).

The overall mean body weight (23.50 kg) presented in the current study was higher than those reported by Tajebe *et al* (2011) for Abergelle sheep (21.25 kg), and by Gebreyowhens and Tesfay (2016) for Tigray Highland sheep (22.10 kg), while the values were lower than those reported by Hayelom *et al* (2014) for Tigray Highland sheep (27.52 kg), and Melaku *et al* (2019) for Simien sheep (24.90 kg) which show their difference from the sheep populations of the neighboring areas. Although the body weight of rams and ewes presented in this study were higher than those reported for

Figure 7. Highland sheep flock in Tahtay Maichew district.

Abergelle and Tigray highland sheep (Tajebe *et al*, 2011; Gebreyowhens and Tesfay, 2016), other traits such as body length, height at withers, heart girth and tail length were comparable between these sheep populations. On the other hand, higher values for all morphological measurements were reported by Edea *et al* (2010) for the country's most known sheep breeds (Bonga and Horro sheep).

The results also revealed that linear body measurements among the studied sheep population differ with age. Three-year-old sheep showed the highest values for most of the measurements, reflecting the optimum growth age. These results are in contrast with results of Getachew *et al* (2009) for Menz and Afar sheep and Melaku *et al* (2019) for Simien sheep who reported that the body weight of the sheep continued to increase with age.

In addition to the quantitative measurements, the qualitative characteristics of a population also allow to easily differentiate genetic resources. Among the obvious qualitative characteristics which differentiate the current sheep populations from the previously characterized sheep populations are the complete absence of beard, horn, ruff, toggle and pigmented skin. Similarly, variations in coat color were also observed among the different agro-ecological zones. Accordingly, the majority of the highland and midland sheep populations from the current study possess tan coat color which makes them unique among the other Tigray highland sheep populations. Sheep populations sampled from the lowland area display dominantly white and light colors which is in agreement with the report of Getachew *et al* (2009) for the lowland Afar sheep. The majority of the sheep populations from the current study possessed hairy fiber type coats, which was in contrast to the results of Hayelom *et al* (2014), who report course wool for Tigray Highland sheep. However, huge variations were not observed among the other qualitative characteristics of the sheep types from the current study and earlier studies of Gebreyowhens and Tesfay (2016) and Hayelom *et al* (2014) for Tigray Highland sheep.

Discriminant function analysis allowed the classification of an average 66% of the studied animals into their respective environments zone. Lowest classification of individuals into their respective agro-ecological zone was observed in midland sheep populations, indicating a lack of uniqueness within them. All of the pairwise comparisons between populations from different agro-ecological zones were found to be highly significant with the largest difference observed between the highland and lowland sheep populations. These results reflect the large altitudinal differences between the two agro-ecological zones. The shortest distance calculated between the lowland and midland sheep populations show their relative similarities as compared with the highland sheep. These differences among different agro-ecological zones show the presence of potential genetic resource variations which can be useful for maintaining diversity and further selection-based genetic improvement programs.

In conclusion, using a combination of quantitative and qualitative characteristics we were able to discriminate the sheep populations from three agro-ecological zones in the Tahtay Maichew district, Tigray region of Ethiopia and to group them into two distinct populations (the highland and the lowland sheep). Sheep populations from the midland agro-ecological zone were considered to be part of the lowland group. Therefore, it is better to consider the highland and lowland sheep as different traditional populations until molecular characterization results provide further evidence for population differentiation. Additionally, the molecular characterization studies will show the within population genetic diversity and level of inbreeding which can be used for selecting appropriate genetic improvement plans (selection or crossbreeding). According to the reports of Gizaw *et al* (2008), the sheep genetic resources of most parts of the Tigray region were generally referred as Sekota sheep population under the short fat tailed breed. However, results from our study indicate that there are several sheep populations that cannot be categorized under the Sekota traditional sheep population. Therefore, it is advisable to include these genetic resources for further molecular studies to understand the genetic diversity within and among populations.

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Author contributions

All authors contributed to the study conception and design. Material preparation, and data collection were performed by AH, TA, SS and ST. Data analysis and writing the first draft of the manuscript was performed by AM and AH. AA commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conflict of interest statement

The authors declare no conflicts of interest.

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