Application of Multivariate Analysis for the Differentiation of Indigenous Goat Populations of South Gondar, Ethiopia

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Abstract: *The study was carried out to describe the indigenous goat population structure in selected districts (Fogera, Farta and Libokemkem) of South Gondar zone by applying multivariate analysis on morphometric variables. Fourteen morphometric traits were taken from 153 male and 357 female goats. The results indicated that the district had a significant effect on all traits of male goats except for body length (BL), height at wither (HW), height at rump (HR), ear length (EL) and scrotal circumference. The district effect in females was also significant for BL, heart girth (HG) and chest depth, paunch girth (PG), HR, and teat length. Age had a highly significant effect on all traits except for EL showing a high heterogeneity among males and females of different flocks. The cluster analysis showed two distinct groups in which Farta goats were included in one cluster while group two included the Fogera and Libokemkem goats under one sub-cluster. The canonical discriminant analysis indicated that Fogera and Libokemkem goats were the closest while the Farta and Fogera goats were the furthest. However, the Mahalanobis distances between the three goat populations were too small indicating the existence of homogeneity among them. The discriminant analysis correctly assigned the respective 58.6%, 62.3% and 63.2% of the Farta, Fogera and Libokemkem goat populations into their source population with an overall 61.4% accuracy rate. In conclusion, multivariate analysis identified BL, HG, HW, PG, HR, canon circumference, rump length, and width as the most imperative traits to effectively differentiate the indigenous goat populations in the studied districts.*

Keywords: Indigenous goats, Morphometric traits, Multivariate analysis, South Gondar

1. Introduction

Goat production in many developing nations like Ethiopia is one of the major means of improving the livelihoods of poor livestock keepers, reducing poverty, and attaining sustainable agriculture and universal food security. They are the most important livestock species for many smallholder farmers and pastoral communities due to their low maintenance requirements, excellent prolificacy, short generation interval, and potential to adapt a wide range of agro-ecological zones (Peacock, 2005; Okpeku *et al*., 2011). They can easily produce and reproduce on shrubs and trees in adverse harsh environments (including tsetse infected areas) where no other crops can be cultivated. However, more than half of the local breeds in the world are threatened and have not been fully characterized (Arandas *et al*., 2017).

The population of goats in Ethiopia is estimated at 38.96 million (CSA, 2018/19). The size of goat populations in Ethiopia has increased more rapidly (134%) than the sheep (65%) and cattle (38%) indicating their growing importance in the livestock agriculture of the country. They are commonly reared in crop-livestock and agro-pastoral farming systems, and are widely distributed across different agro-ecological zones of Ethiopia (Gizaw *et al*., 2010; Seid, 2017). The majority of them are found in the lowland pastoral and agro-pastoral production systems where pastoralists in the South, East, and West keep them mainly for milk and meat production purposes (Gizaw *et al*., 2010). Goats reared in the mid- and highlands are widely distributed in the crop-livestock production systems with varying flock sizes as a means of cash earnings and meat.

Despite the huge resource perspective, there is limited information on the real genetic potentials of local goat populations that are distributed in various regions of the country. Phenotypic characterization study is the basis for the differentiation of indigenous animal genetic resources and provides useful information in designing appropriate genetic improvement programs for their sustainable utilization and conservation. Such studies mainly depend on the knowledge of the variation of morphological traits, which are important elements in the classification of livestock based on appearance, size and shape (Okpeku *et al.*, 2011; Melesse *et al*., 2013). There are different studies carried out by various scholars to characterize the indigenous goat populations of Ethiopia and most of them reported the existence of phenotypic variations between and within the studied goat ecotypes (Alemu, 2004; Hassen *et al*., 2012; Gatew *et al*., 2015; Mekuriaw, 2016). However, there is still limited characterization studies conducted to describe the population structure and genetic potentials of indigenous goat populations found in Amhara Regional State in general and that of South Gondar in particular. For example, Hassen *et al*. (2012) conducted a morphological characterization study on indigenous goats in some zones of the Amhara Region. Although South Gondar zone was considered as one of them, the respective potential districts for goat production were not adequately represented due to limited samples included in that particular study. As a result, the population structure of the indigenous goats in South Gondar zone has not been adequately described. Therefore, this study was conducted to differentiate the indigenous goat populations based on their morphometric traits by applying the multivariate analysis.

2. Materials and Methods

2.1. Site selection and sampling techniques

The study was conducted in three districts of South Gondar zone in the Amhara Regional State, Ethiopia. First, the relevant second-hand information was gathered from the Agriculture and Rural Development office of livestock. Based on the information obtained, multi-stage purposive sampling techniques were applied to select the study districts and kebeles (the smallest administrative unit within the district). In the first stage, three districts namely Farta, Fogera and Libokemkem were selected purposively based on their goat population size and potential. In the second stage, three kebeles from each district were selected purposively based on the distribution of the goat populations. In the third stage, the farmers who own at least five or more matured goats of both sexes were identified within kebeles. Accordingly, 306 goats from Farta and Fogera and the 204 goats from Lobokemkem districts with a total number of 510 were sampled of which 153 and 357 were male and female goats, respectively. The owner's recall method along with dentition classes (pairs of permanent incisors, PPI) was used to estimate the ages of the goats. Accordingly, goats with 1PPI, 2PPI, 3PPI and 4PPI were classified in the age groups of yearling, 2-year-old, 3-year-old and 4-year-old and above, respectively (Ebert and Solaiman, 2010). Each animal was further identified by its sex and sampling site.

2.2. Types of data collected

Data on 14 morphometric traits were collected according to the descriptor list of FAO (2012) for phenotypic characterizations of goats. Accordingly, the following traits were measured: live body weight (LW), body length (BL), height at withers (HW), heart girth (HG), chest depth (CD), chest width (CW), paunch girth (PG), rump height (RH), rump length (RL), rump width (RW), ear length (EL), fore cannon circumference (FCC), teat length (TL) and scrotal circumference (SC). All morphometric traits were taken using plastic tape while body weight using a suspended weighing scale with 50 kg capacity by placing each animal in self-devised holding equipment. All linear body measurements were taken early in the morning before goats leave for browsing.

2.3. Statistical Analysis

Since the sample size was unbalanced among different districts and age groups, data were subjected to GLM procedures by fitting district and age as fixed effects. Since the interaction effect of district by age was insignificant, it was dropped from the analysis. The sex groups (males and females) were analyzed separately due to considerable differences in sample size. When F-test declared significant, means were separated by Least Square Means procedures. Accordingly, least squares means with SE were presented rather than the arithmetic mean. The procedure of the Cluster analysis was performed and a dendrogram graph was constructed based on Euclidean distance to differentiate the goat populations of the three districts using the average linkage method to group the flocks into their morphological similarity. Moreover, the stepwise discriminant analysis was applied using the STEPDISC procedure to determine which the morphometric variables have more discriminating power. The relative importance of the morphometric variables in discriminating the three goat populations was assessed using the level of significance, F-statistic and partial R^2. Collinearity among the variables used in the discriminant model was also evaluated using tolerance statistics. The canonical discriminant analysis was then performed on the identified variables with the most discriminating power using the CANDISC procedure which computed the Mahalanobis distances between class means, uni- and multivariate statistics, and canonical variables with eigenvalues. The TEMPLATE and SGRENDER procedures were also applied to create a plot of the first two canonical variables in a scatter graph for visual interpretation. Finally, discriminant analysis of the DISCRIM procedure was conducted to determine the percentage classification of goats into their source populations using a quadratic discriminant function for the unequal covariance matrices within classes after checking with the Bartlett's homogeneity test. The classification accuracy of the discriminant analysis was further cross-validated by invoking the CROSSVALIDATE option. All multivariate analyses were performed using the Statistical Software of SAS (2012, ver. 9.4).

3. Results

3.1. Morphometric traits

In males, as shown in Table 1, the district showed different influences across traits varying between highly significant (LW, HG, CD, CW, RL, RW and FCC) and non-significant (BL, HW, HR, EL and SC). Fogera male goats had larger HG ($p<0.05$) than those of Farta and Libokemkem while no difference was noted between the latter two. Chest width and CD values were larger ($p<0.05$) for Farta and Fogera male goats than those of Libokemkem. Male goats of Farta had larger ($p<0.05$) RL and RW values than those of Fogera and Libokemkem while those of Fogera had larger RL than those of Libokemkem. A significantly bigger FCC was observed in the male goat populations of Farta and Libokemkem than those of Fogera.

The effect of the district in females was significant for BL, HG, CD, PG, HR, and TL (Table 2). Accordingly, the female goats of Libokemkem had higher BL than those of Farta and Fogera. The latter two did not significantly differ from each other for the same trait. On the other hand, the female goats of Fogera and Farta had larger HG than those of Libokemkem. Likewise, the female goats of Farta had larger CD and PG than those of Fogera and Libokemkem. No significance difference was noted between the latter two. A significantly higher RH was observed in the female goat populations of Fogera than those of Libokemkem and had larger RL than those of the Farta. No significant difference was found in RH and RL values between Farta and Libokemkem female goat populations. The female goats of Farta had higher EL and TL than those of Libokemkem. Teat length of goats from the Fogera district was larger than that of Libokemkem. The effect of age in both sexes was highly significant for all traits except for EL showing a large heterogeneity among males and females of different flocks.

Table 1: Least squares means of live weight (kg) and linear body measurement traits (cm) of indigenous male goat populations as affected by district and age (N= 153)

Morphometric traits	District			Overall mean (±SEM)	Age				Overall mean (±SEM)	Fixed effects	
	Farta	Fogera	Libo-kemkem		1PPI	2PPI	3PPI	4PPI		District	Age
Live weight	31.0[b]	31.7[a]	31.0[b]	31.2±0.16	26.7[d]	29.2[c]	33.6[b]	35.4[a]	31.2±1.99	0.001	<.0001
Body length	62.4	62.3	62.2	62.3±0.23	58.4[d]	60.4[c]	64.5[b]	66.1[a]	62.4±1.78	0.576	<.0001
Height at withers	69.7	69.9	69.8	69.8±0.13	66.3[d]	68.6[c]	71.4[b]	72.8[a]	69.8±1.45	0.434	<.0001
Heart girth	72.9[b]	73.9[a]	73.3[b]	73.4±0.15	70.2[d]	72.2[c]	75.0[b]	76.2[a]	73.4±1.36	<.0001	<.0001
Chest depth	31.8[a]	31.7[a]	31.3[b]	31.6±0.14	28.5[d]	30.8[c]	32.9[b]	34.2[a]	31.6±1.25	0.008	<.0001
Chest width	17.1[a]	16.9[a]	16.6[b]	16.9±0.11	14.8[d]	16.3[c]	17.7[b]	18.6[a]	16.9±0.83	0.002	<.0001
Paunch girth	78.4[ab]	79.3[a]	78.1[b]	78.5±0.34	74.0[d]	77.2[c]	80.3[b]	82.8[a]	78.6±1.91	0.014	<.0001
Height at rump	72.0	72.1	72.2	72.1±0.17	68.8[d]	71.2[c]	73.5[b]	74.9[a]	72.1±1.34	0.821	<.0001
Rump length	16.7[a]	15.9[b]	15.4[c]	16.0±0.13	14.9[d]	15.6[c]	16.3[b]	17.4[a]	16.1±0.53	<.0001	<.0001
Rump width	14.5[a]	12.9[b]	13.2[a]	13.5±0.16	11.5[d]	13.5[c]	14.1[b]	15.1[a]	13.6±0.76	<.0001	<.0001
Fore canon circumference	8.19[a]	7.71[b]	8.35[a]	8.08±0.14	7.38[b]	7.70[b]	8.52[a]	8.74[a]	8.09±0.32	0.004	<.0001
Ear length	14.8	14.6	14.9	14.7±0.15	14.7	14.7	14.7	15.0	14.8±0.08	0.237	0.581
Scrotal circumference	23.1	23.3	23.0	23.1±0.15	21.9[b]	23.1[ab]	23.7[a]	23.9[a]	23.2±0.45	0.332	<.0001

[a,b,c,d] Means within district and age groups with different superscript letters are significant at $p<0.05$; SEM = standard error of the mean

Table 2: Least squares means of live weight (kg) and linear body measurement traits (cm) of indigenous female goat populations as affected by district and age (N = 357)

Morpho-metric traits	District			Overall mean (±SEM)	Age				Overall mean (±SEM)	Fixed effects	
	Farta	Fogera	Libo-kemkem		1PPI	2PPI	3PPI	4PPI		District	Age
Live weight	27.7^{b}	28.1^{a}	28.0^{a}	27.9±0.10	24.1^{d}	26.5^{c}	29.3^{b}	31.9^{a}	28.0±1.69	0.145	<.0001
Body length	60.2^{a}	60.1^{a}	59.5^{b}	59.9±0.11	56.6^{d}	58.7^{c}	60.8^{b}	63.7^{a}	60.0±1.52	<.0001	<.0001
Height at withers	67.4^{a}	67.6^{a}	67.6^{a}	67.5±0.81	64.4^{d}	66.4^{c}	68.6^{b}	70.7^{a}	67.5±1.36	0.639	<.0001
Heart girth	70.7^{b}	71.2^{a}	71.3^{a}	71.0±0.10	68.0^{d}	70.1^{c}	72.2^{b}	73.8^{a}	71.0±1.26	0.015	<.0001
Chest depth	30.0^{a}	29.7^{b}	29.6^{b}	29.8±0.08	26.8^{d}	28.5^{c}	31.0^{b}	32.8^{a}	29.8±1.33	<.0001	<.0001
Chest width	15.4	15.4	15.4	15.4±0.07	13.7^{d}	15.1^{c}	16.0^{b}	16.8^{a}	15.4±0.66	0.283	<.0001
Paunch girth	75.6^{a}	74.7^{b}	74.4^{b}	74.9±0.16	70.6^{d}	72.7^{c}	77.3^{b}	79.0^{a}	74.9±1.96	<.0001	<.0001
Height at rump	70.3^{b}	70.6^{a}	70.3^{b}	70.4±0.09	67.5^{d}	69.4^{c}	71.7^{b}	73.1^{a}	70.4±1.24	0.008	<.0001
Rump length	15.9^{b}	16.2^{a}	16.1^{ab}	16.0±0.06	15.1^{d}	15.7^{c}	16.4^{b}	17.1^{a}	16.1±0.43	0.051	<.0001
Rump width	13.2^{a}	12.8^{a}	13.1^{a}	13.0±0.12	11.0^{c}	13.2^{b}	13.9^{a}	14.0^{a}	13.0±0.70	0.236	<.0001
Fore canon circumference	7.94^{a}	7.76^{a}	7.89^{a}	7.86±0.08	7.08^{c}	7.69^{b}	7.95^{b}	8.71^{a}	7.86±0.34	0.209	<.0001
Ear length	14.7^{a}	14.6^{a}	14.4^{a}	14.5±0.09	14.4	14.6	14.6	14.6	14.6±0.04	0.095	0.686
Teat length	3.71^{a}	3.72^{a}	3.66^{a}	3.70±0.02	3.04	3.49	4.02	4.24	3.70±0.27	0.007	<.0001

^{a,b,c,d} Means within district and age groups with different superscript letters are significant at $p<0.05$; SEM = standard error of the mean

3.2. Multivariate Analysis

As indicated in Figure 1, the cluster analysis generated a phylogenetic tree that clustered the goat populations of South Gondar into two main groups based on morphometric traits. The first group included goat populations from Farta district while the second group includes those from both Fogera and Libokemkem districts as sub-cluster. Table 3 presents the results of the stepwise discriminant analysis showing Wilk's Lambda, F-values, probability and tolerance statistics. Twelve quantitative traits were subjected to the STEPDISC analysis of which eight were identified as the best discriminating variables. Wilk's lambda test confirmed that all the selected variables had highly significant (p<0.0001) contribution to differentiate the total population into separate groups. The variables with the highest discriminating power were BL, HG, HW, PG, HR, RL, RW and FCC (Table 3). The remaining four variables (LW, CD, CW and EL) had poor discriminating power and were excluded in the subsequent analysis.

All the eight variables were then subjected to canonical discriminant analysis using the CANDISC procedure. The univariate statistics testing the hypothesis that class means are equal which validate that each quantitative variable in sampled populations is a significant (p<0.0001) contributor to the total variation. The multivariate statistics for differences between the districts was also significant (p<0.0001). The hypotheses that assumes the districts' means are equal in the populations was rejected by the Wilk's Lambda (p<0.0001) indicating that differences found between studied districts were statistically different from zero.

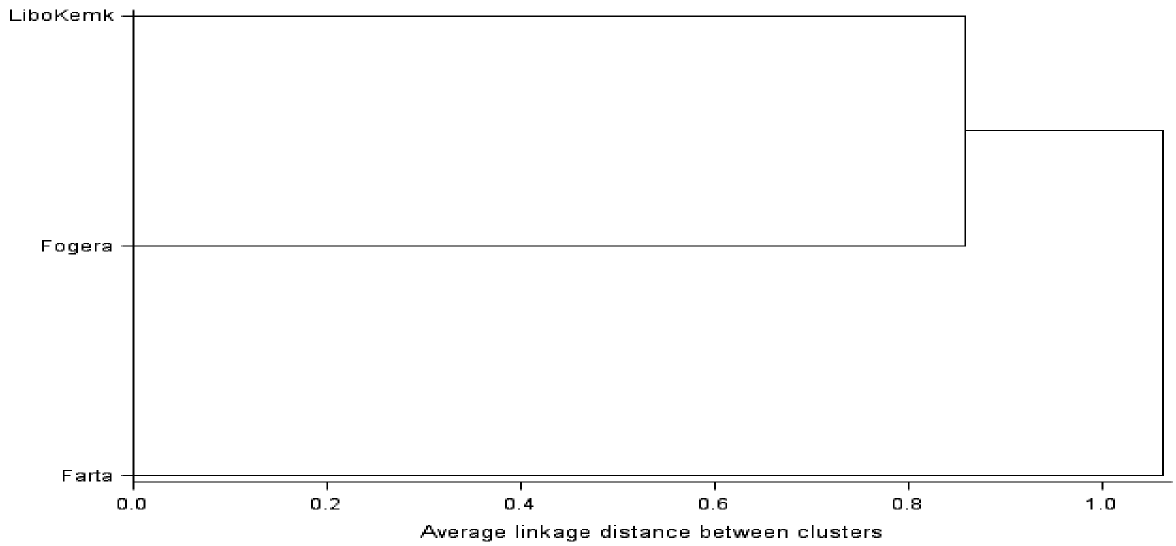

Figure 1: Dendrogram based on average linkage distance between goat populations reared in the three districts of South Gondar using morphometric variables

Table 3: Summary of stepwise discriminant analysis for selection of traits

Step	Variables entered	Pr > F	Wilks' Lambda	Pr<Lambda	ASCC	Pr>ASCC	Tolerance
1	Rump width	0.001	0.9743	0.0013	0.0129	0.0013	0.870
2	Heart girth	<.0001	0.9284	<.0001	0.0358	<.0001	0.687
3	Body length	<.0001	0.8679	<.0001	0.0672	<.0001	0.283
4	Puanch girth	0.003	0.8476	<.0001	0.0779	<.0001	0.239
5	Fore canon circumference	0.004	0.8295	<.0001	0.0882	<.0001	0.233
6	Height at wither	0.113	0.8223	<.0001	0.0923	<.0001	0.129
7	Rump length	0.051	0.8126	<.0001	0.0977	<.0001	0.124
8	Height at rump	0.104	0.8053	<.0001	0.1019	<.0001	0.084

ASCC = average squared canonical correlation

The Mahalanobis distances and probability values for the contrast among the goat populations of the three districts are presented in Table 4. All Mahalanobis distances were significant ($p < 0.0001$). The shortest distance (0.401) was observed between the goat populations of Fogera and Libokemkem districts while the larger between those of Fogera and Farta (0.872). The Mahalanobis distance between Farta and Libokemkem goat populations was 0.858, which is much similar to those of the Farta and Fogera.

Summary of canonical correlations and eigenvalues are presented in Table 5. The multivariate statistics for differences between the districts was significant ($p<0.0001$). Standardized coefficients for the canonical discriminant function, the canonical correlation, the eigenvalues and share of total variance accounted for this study revealed that both canonical variables determined (CAN1 and CAN2) was significant. The CAN1 and CAN2 accounted for 70% and 30% of the total variation, respectively. Table 5 further displayed the likelihood ratio test of the Rao's F approximation, which rejected the hypothesis that assumes the current canonical correlations and all smaller ones are zero.

Figure 2 shows a plot built with the two canonical variables illustrating the relationships between goat populations belonging to different districts. The plot displayed that CAN1 discriminates between the two districts: Farta and Fogera while CAN2 best discriminates between Libokemkem and the other two districts. However, it can be observed in the figure that there is a visible overlapping among the three goat populations indicating the existence of homogeneity.

Table 4: Pairwise Mahalanobis distance values among the three goat populations

Districts	Farta	Fogera	Libokemkem
Farta	0	0.872	0.858
Fogera	0.872	0	0.401
Libokemkem	0.858	0.401	0

All distances are significant at $p<0.001$

Table 5: Summary of canonical correlations, eigenvalues and likelihood ratios

Functions	Canonical correlations	Eigenvalues			Likelihood ratio	Approximate F-value	Pr>F
		Eigen-value	Proportion	Cumulative			
CAN1	0.373	0.161	0.70	0.700	0.805	7.15	<0.0001
CAN2	0.254	0.069	0.30	1.000	0.935	4.96	<0.0001

CAN1 = canonical variable 1; CAN2 = canonical variable 2

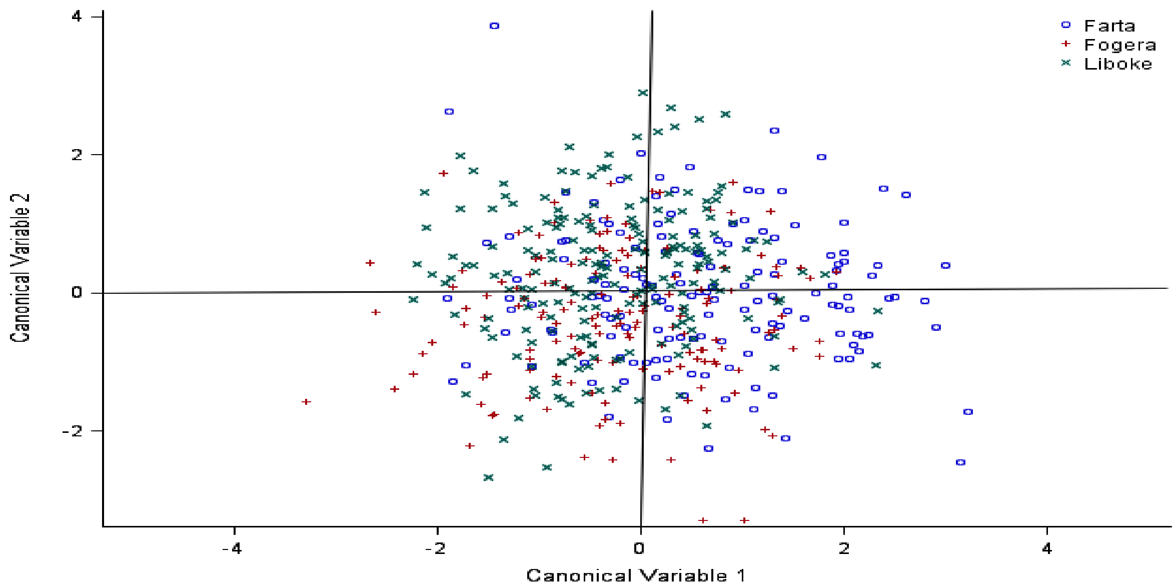

Figure 2: Canonical representation of the goat population in the three districts of South Gondar

Discriminant analysis assumes that the individual group covariance matrices are equal (homogeneity within covariance matrices) and by default, it uses the linear discriminant function for classification.

In the current discriminant analysis, equality of covariance matrices within groups was tested using Bartlett's test of homogeneity for all traits and was significant (χ^2 = 248; p<0.0001) by rejecting the null hypothesis that assumes all covariance matrices within the goat populations are homogenous. Therefore, the within-group covariance matrices were used to derive the quadratic discriminant function criterion for the classification of the three goat populations.

As presented in Table 6, the discriminant analysis correctly classified 58.6% of Farta goats into their respective origin population with 22.4 and 19.1% being misclassified to Fogera and Libokemkem goat populations, respectively. Similarly, 62.3% of Fogera goats were correctly assigned to their source population while the remaining 14.9 and 22.7 being misclassified to Farta and Libokemkem goat populations, respectively. The quadratic discriminant function further differentiated the Libokemkem goat from others with 63.2% correct classification into their original source population with the remaining 13.7 and 23.0% being misclassified to Farta and Fogera goat populations, respectively. The overall error count estimates provide the proportion of misclassified observations in each group being highest in Farta goats (41.4%) and lowest in those of Libokemkem (36.8%).

The classification accuracy of the discriminant analysis was further cross-validated and indicated an overall 53.0% success rate (Table 6). The error count estimate for the cross-validation was 46.7, 50.7, and 43.6% for Farta, Fogera and Libokemkem districts, respectively. The overall error count estimate for classification was 38.6% while it was 47.0% for cross-validation option. It would be worthwhile to note that the cross-validation option achieved a fairly unbiased estimate with a relatively large variance.

Table 6: Percent of individual goats classified into their respective districts and cross-validation of classification based on morphometric variables (values in brackets are number of goats)

Districts	Farta	Fogera	Libokemkem	Total
Re-substitution				
Farta	58.6 (89)	22.4 (34)	19.1 (29)	100 (152)
Fogera	14.9 (23)	62.4 (96)	22.7 (35)	100 (154)
Libokemkem	13.7 (28)	23.0 (47)	63.2 (129)	100 (204)
Error count estimate	0.414	0.377	0.368	0.386
Priors	0.333	0.333	0.333	-
Cross-validation				
Farta	53.3 (81)	25.0 (38)	21.7 (33)	100 (152)
Fogera	18.2 (28)	49.4 (76)	32.5 (50)	100 (154)
Libokemkem	16.2 (33)	27.5 (56)	56.4 (115)	100 (204)
Error count estimate	0.467	0.507	0.436	0.47

4. Discussion

4.1. Quantitative traits

Height at withers and EL were not affected by the district in both sex groups which indicates their similarity in their heights and the size of the ears. In male goats, the district did not affect BL, HR and SC. Similarly, LW, CW, RL and RW in females were not affected by the district. These observations suggest that the genetic improvement of these traits in both sexes of the studied districts might be justifiable. Age of the goats had a significant (P<0.05) effect on all linear body measurement traits except for EL in both sexes. Most of the morphometric traits increased with age, which is in close agreement with the findings of Lorato *et al*. (2015) for Woyto Guji goat type in Loma district. A linear increment of morphometric traits with age indicates a normal body development of goats which suggest the suitability of the production environment for goat rearing. The absence of an increase in the size of ear in both sexes may suggest its limited importance during the physical development of the goats.

In the present study, male goats appeared to be heavier than females. This might be explained by the presence of a high level of the hormone androgen in bucks, which is responsible for muscular growth. This observation was in agreement with that of Seid *et al*. (2016) who reported similar findings in goats reared in the Western highland of Wollega zone, Oromia. On the contrary, Jeda and Asefa (2016) reported that females goats raised in the Bale zone had higher LW than those of bucks. Such inconsistencies might be due to differences in age, breed, management, and accuracy of taking measurements in which the data were collected. Moreover, such differences might be attributed to the result of negative selection practiced by the farmers as fast-growing male kids are sold at an earlier age. Female goats had higher RL than males and FCC and RW values almost the same for both sexes. Rump size is a very important structure for ease deliverance.

The SC is an important trait that is closely associated with the testicular growth and sperm production capacity of domestic animals. Gatew *et al*. (2015) reported relatively higher SC values for bucks in eastern Ethiopia than observed in the current study (27 vs. 23 cm). Since SC size is dependent on the maturity of the animal, the differences could be attributed to the age of bucks when data were collected. This has been supported by the present observation in which SC has been significantly affected by age. Moreover, SC showed a significant positive correlation with the live weight of goats (Tade *et al*., unpublished data), which substantiated the dependency of SC on the body development of the animal. Consistent with the current results, Raji and Ajala (2015) observed a significant effect of body weight on SC for West African Dwarf buck. As SC is an indirect measurement of testicular size, knowing the increased size of testis may be used as an indicator in the onset of active spermatogenesis and, hence, the possibility of using bucks for breeding at an earlier age than normally recommended. Such knowledge might be particularly essential if young bucks may not be kept together with the does for reasons related to control of the occurrence concurrence of inbreeding as well as disease transmission during mating.

The teat length positively affected milk production potentials of does (El-Gendy *et al*., 2014). Merkhan and Alkass (2011) reported 3.6 cm TL for Iraqi Black and Meriz goats, which is comparable with the current findings (3.7 cm). The overall teat length of goats in the present study is comparatively higher than reported by Alemayehu *et al*. (2015) for goats of West Amhara (3.7 vs. 3.40 cm). Teat length is significantly affected by the age of the does, which indicates a linear increase in teat size with the advancing age. In general, the goat populations of Fogera district had the highest BW and HG values as compared to those of Farta and Libo-kemkem districts. However, the goats of the Farta district had the highest CD. The observed variations might associated with differences in the management practices among the communities and the availability of feed and water resources.

4.2. Multivariate Analysis

The Cluster analysis classified the goat populations in two main groups based on their morphometric traits in which the first group included the Farta goat populations while the second group includes the Fogera and Libokemkem goats as sub-cluster. This observation indicates that goats of the Fogera and Libokemkem districts are much closer to each other than those of the Farta and confirmed the results of the cross-classification of population distribution with discriminant analysis.

Except for height at rump, the tolerance values obtained from the present study were greater than 0.1. This is an indication that there was no collinearity problem among the eight most discriminating morphometric variables (Yakubu *et al*., 2010; Selolo *et al*., 2015). Some of the present discriminant variables are similar to those reported by Yakubu *et al*. (2011) for West African Dwarf and Red Sokoto goat breeds.

All Mahalanobis distances were significant which are in line with the findings of Zaitoun *et al*. (2005). The Mahalanobis distance was relatively short for the goat populations of Fogera and Libokemkem districts, indicating that they are homogenous in their morphometric characters probably due to sharing similar genetic identities. This trend has been demonstrated in the dendrogram displayed in Fig. 1. The low Mahalanobis distances between Fogera and Libokemkem goat populations might have resulted from non-selection, continuous inbreeding, and high intermingling rate between these two populations in an open management system of production, which is commonly practiced by many rural communities. Moreover, the two districts (Fogera and Libokemkem) are sharing quite a substantial area of borderline which affirms the homogeneity of the genetic identity of the goats resulting from intermix of genetic materials. On the other hand, the Mahalanobis distance was comparatively larger between goat populations of Farta and Libokemkem as well as between those of Farta and Fogera districts. Comparative large Mahalanobis distances were reported between Damascus and Dhaiwi goat breeds while a moderate distance was observed between Mountain and Dhaiwi (Zaitoun *et al*., 2005). In general, the Mahalanobis distances between the three goat populations were too short indicating the existence of homogeneity among the studied goat populations.

The univariate statistics testing the hypothesis that class means are equal shows that each quantitative variable in sample populations except HG, HW and HR was significant ($p<0.05$) contributor to the total variation. The Wilks' lambda, the ratio of within-group variability to total variability on the discriminator variables, is an inverse measure of the importance of the discriminant functions. The Wilks' lambda test (Table 5) for the population was 0.805, which reflects less part (19.5%) of the variability in the discriminator variables was because of the differences between populations rather than variation within the population.

In the current study, CAN1 and CAN2 accounted for 70% and 30% of the total variation, respectively, indicating a complete representation of individuals of the local goat populations with one scatter plane. The extracted both canonical variables were found to be significantly different, which agrees with the observations of Traoré *et al*. (2008) for goat populations of Burkina Faso. On the contrary, Selolo *et al*. (2015) reported that the CAN1 was significant while CAN2 remained insignificant for local South African goats. There are indeed conflicting reports in the literature on the proportion of total variation explained by both canonical variables (CAN1 and CAN2). For example, Traoré *et al*. (2008) reported a total variation of 94.0% and 5.5% for CAN1 and CAN2, respectively while the corresponding values were 82.4% and 10.7% for Jordan native goat breeds as reported by Zaitoun *et al*. (2005). Selolo *et al*. (2015) reported that 91.9% of the total variation was accounted by CAN1 while only 8.1% by CAN2. The reported differences in the literature might be explained by the sample size, age and breed of goats studied. Rump width, PG, RL and BL dominated CAN1, while FCC showed the largest influence on CAN2. Herrera *et al*. (1996) found that head length and withers height were the most important variables in CAN1, while head width and shin circumference were the most important variables in CAN2 in their discrimination among the five Andalusian goat breeds.

The values computed for CAN1 and CAN2 for each individual were plotted by districts and displayed in Figure 2. Accordingly, the Farta individuals appeared to relatively homogeneous and clustered together on the right hand of the X-axis; the Libokemkem are mainly distributed on the positive values of the Y-axis, and the Fogera individuals showed an intermediate distribution but inclined toward to the Libokemkem goats. In this respect, the discriminant analysis carried out provided complementary information (Table 6) in which most of the goat populations of Libokemkem and Fogera districts were classified into their source population (63.2% and 62.3%, respectively) whilst the rest (13.7 and 14.9) were misclassified as Farta individuals. The discriminant analysis also classified 58.6% Farta individual indigenous goats into their original districts. Similarly, Selolo *et al*. (2015) found that 60.3, 58.1 and 38.5% of the individual goats were classified into their original agro-ecological zones with several individuals being misclassified. Yakubu and Ibrahim (2011) reported that Yankasa (45.9%), Uda (33.5%) and Balami (61.5%) sheep breeds were correctly classified into their source group. Another study conducted by Dossa *et al*. (2007) indicated that more than 70% of individual goats were correctly allocated to their different source groups. Similarly, the respective 79.3% and 82.7% of Sudan and Sudan-Sahel goat populations of Burkina Faso were classified into their source population (Traoré *et al*., 2008). Dekhili *et al*. (2013) reported that 73%, 66.8% and 79.3% of Algeria goats were classified into North, Center and South environments, respectively. Yakubu *et al*. (2010) reported that only 24.4% of rainforest and 22.9% of guinea savanna goats were correctly classified into their source populations. These reports suggest the importance of multivariate discriminant analysis to differentiate indigenous livestock populations that are being reared in various production environments.

Based on the discriminant analysis, the overall average error count estimate was 38.6% for all observations and 61.5% of the overall sampled populations were correctly classified to their origin districts indicating the heterogeneity of goat populations within districts for those variables included in the discriminant analysis. The relatively higher errors of classification for Farta goats may indicate that they might have been extensively mixed with the other local goat populations. The misclassification observed in this study may also suggest that the level of genetic exchange that has taken place overtime between the goats reared in the three districts. In addition, there is a good possibility of admixture among these goats because of the continuous migration of flocks that existed for many generations. Moreover, the assignment errors of local goat breeds might have occurred between goat populations reared in the same production system. Such speculations might be justifiable, as goats reared under the same production system might have been selected naturally and artificially for similar traits (Zaitoun *et al*., 2005).

The low differentiation assessed between Farta and Fogera and between Farta and Libokemkem goats using the Mahalanobis distances and the large classification errors obtained using the discriminant analysis did not give statistical support to separate these goat populations into different distinct ecotypes. Moreover, a significant proportion of cross-classification errors (41.5%) observed in Farta goat populations suggests that they might share a similar genetic basis with the other two goat populations. Such admixtures are possible due to the existence of an active marketing system of goats in the region.

5. Conclusion

Bucks of Fogera district had larger heart girth than those of Farta and Libokemkem while the females of Libokemkem district had higher body length than those of Farta and Fogera. The cluster analysis showed two separate clusters: cluster one included the Farta goat populations as one distinct group while cluster two included the Fogera and Libokemkem goats under one sub-cluster. The canonical discriminant analysis verified similar trend by indicating the Fogera and Libokemkem goats are the closest while the largest Mahalanobis distance was between Farta and Fogera goat populations with all distances being significant. However, the canonical discriminant analysis indicated a visible overlapping among the three goat populations suggesting the existence of homogeneity. The respective 58.6%, 62.3% and 63.2% of the Farta, Fogera and Libokemkem goat populations were correctly classified into their districts with overall error count estimates of 38.6%. The accuracy of the classification was further cross-validated in which the respective 53.3, 49.4 and 56.4 of Farta, Fogera and Libokemkem goats were correctly assigned to their source populations with an overall error count of 47.0%.

Conflict of Interest

The authors declare that there is no conflict of interest.

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