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Research Article

Characterization of Qualitative Morphological Traits in Indigenous Goats in Ethiopia Using Multivariate Analysis

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Abstract

Characterization of goat breeds based on morphological trait variations is essential for planning breed improvement programs and conservation strategies. This study aimed to use multiple correspondence analysis to evaluate qualitative morphological traits and identify traits that best describe the morphological structure of Hararghe goats. The results of the study show that there are significant differences in the distribution of some qualitative morphological traits among the three districts (Bedeno, Fedis, and Gorogutu) while others do not show significant differences. The first principal axis explained 15% of the principal inertia, the second principal axis explained 12%, and cumulatively the first two principal axes explained 27% of the principal inertia. The MCA method identified systematic relationships among traits and trait attributes. On the dimensions identified, the sample goat population of Fedis and Gorogutu clustered together with concave head profile, straight horn shape, obliquely upward horn orientation, presence of Toggle, and pigmented Muzzle; while the corresponding values of goats in Bedeno clustered together with the presence of horn, curved and spiral horn shape, backward and lateral horn and ear orientation with slope down from wither, slope up toward rump, and pendulous. These findings provide valuable information for better multivariate characterization and conservation of indigenous goat ecotypes.

Keywords: Goat; Multiple correspondence; Qualitative traits

Introduction

Ethiopia has a large population of goats (approximately 52.5 million) mainly of indigenous breeds [1] has classified the indigenous goat types into eight distinct genetic units using genetic DNA markers. Indigenous goat populations generally dominate the goat flocks in Ethiopia and have developed certain valuable merits such as the ability to perform better under low input conditions and climatic stress, tolerance to infectious diseases and parasites as well as heat stresses [2,3].

In Ethiopia, farmers/pastoralists keep goats for food, income generation and socio-cultural considerations and as a source of other valuable non-food products such as skin and manure [4,5]. Despite the large size, wide distribution and diversified functions, the Ethiopian goat population productivity is relatively low. This is due to different factors such as poor nutrition, the prevalence of diseases and lack of appropriate breeding strategies and poor understanding of the production system [6]. To increase and sustain the productivity of indigenous goats to respond to the growing domestic and foreign demands for live goats and products, improvement programs are necessary and should be designed, especially for countries like Ethiopia where an extensive production system is predominant.

Characterization studies are essential for planning improvement, sustainable utilization and conservation strategies of a breed at local, national, regional and global levels [7]. In the absence of baseline characterization information, some breed populations and the unique characteristics they possess may decline significantly, or be lost, before their value is recognized and measures are taken to conserve them [7]. In Ethiopia, various goat characterization studies for different goat populations have been executed. In this regard, the assessment of quantitative morphological traits' relationship among small ruminant breeds has been investigated to an extent using multivariate statistics such as Principal Component Analysis (PCA), cluster analysis &/or discriminant analyses [8-12]. However, when it comes to the assessment of qualitative morphological traits, information on the phenotypic characterization using multivariate statistics is still scanty except for a few works [12-15].

So far, in many studies investigating the analysis of qualitative morphological traits, contingency table analysis was used to analyse the data. Contingency tables are easy to set up and easy to understand. Besides, they are useful because little of the statistical concepts are necessary for interpretation and one can easily observe patterns of correlation. However, they have drawbacks including not precisely measuring the nature of the correlation between two traits and traits with many categories requiring large tables that are difficult to manage. Again, categories with few observations obfuscate the bivariate correlation and the Chi-square test cannot provide predicted values. Above all contingency tables can only be used to analyse the effect of a single categorical variable on the response.

Frontier techniques that have traditionally been used to extensively explain relationships of morphological traits extensively are the multivariate techniques. However, multivariate techniques, like multiple correspondence analysis (MCA), have not been fully exploited in the objective description of qualitative morphological traits in Ethiopia. To our knowledge, there is very limited information on describing the qualitative morphological traits of indigenous livestock in Ethiopia using MCA [12-15].

Therefore, the current study was intended to overcome the above limitations by using (MCA) to investigate the relationship among qualitative morphological traits and identify significant traits that best

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describe the morphological structure of the Hararghe goat. The study will thereby increase and promote the adoption of MCA by researchers in the field and help find the relative closeness of the key correlation factors so that necessary actions can be taken to the development of suitable policies for designing breeding programmes and conservation. The study will also benefit farmers in the selection of the best morphological traits that might improve traits of interest during management and selection during the breeding of goats.

Materials and Methods

Description of the study area

East Hararghe is located in the eastern part of Ethiopia, at 510 km distance from Addis Ababa. It has a mean altitude of about 1300 m.a.s.l. The annual mean temperature of the area is 19.2°C. The coldest months are November, December and January and the mean monthly rainfall is 67.11 mm and the mean annual rainfall is 804.7 mm. East Hararghe has 19 districts, from which this study involved three districts; namely Fedis, Gorogutu and Bedeno (Figure 1).

Sampling techniques for data collection

The study was conducted in East Hararghe, a region renowned for its diverse goat population density and the significant role goats play in the livelihood of the local community. Three districts, namely, Fedis, Gorogutu, and Bedeno were purposefully selected due to their substantial goat population density and the high number of farmers engaged in goat rearing. Phenotypic characterization of these goat genetic resources was conducted by collecting qualitative morphological traits from a sample of 100 male and 350 female mature goats, following the recommended descriptors outlined by [7]. A comprehensive record of fifteen qualitative morphological traits was obtained for the goat population in the selected districts. These traits encompassed various aspects such as coat colour pattern (patchy, plain, spotted), head profile (concave, convex, straight), horn characteristics including shape (curved, spiral, straight) and orientation (backward, lateral, obliquely upward), ear orientation (erect, pendulous), back profile (slope down from the withers, slope up toward the rump, straight), hair length (large, medium, small) and type (glossy, smooth), presence or absence of wattles, ruff, beard, toggle, muzzle pigmentation, and rump profile (sloppy, straight).

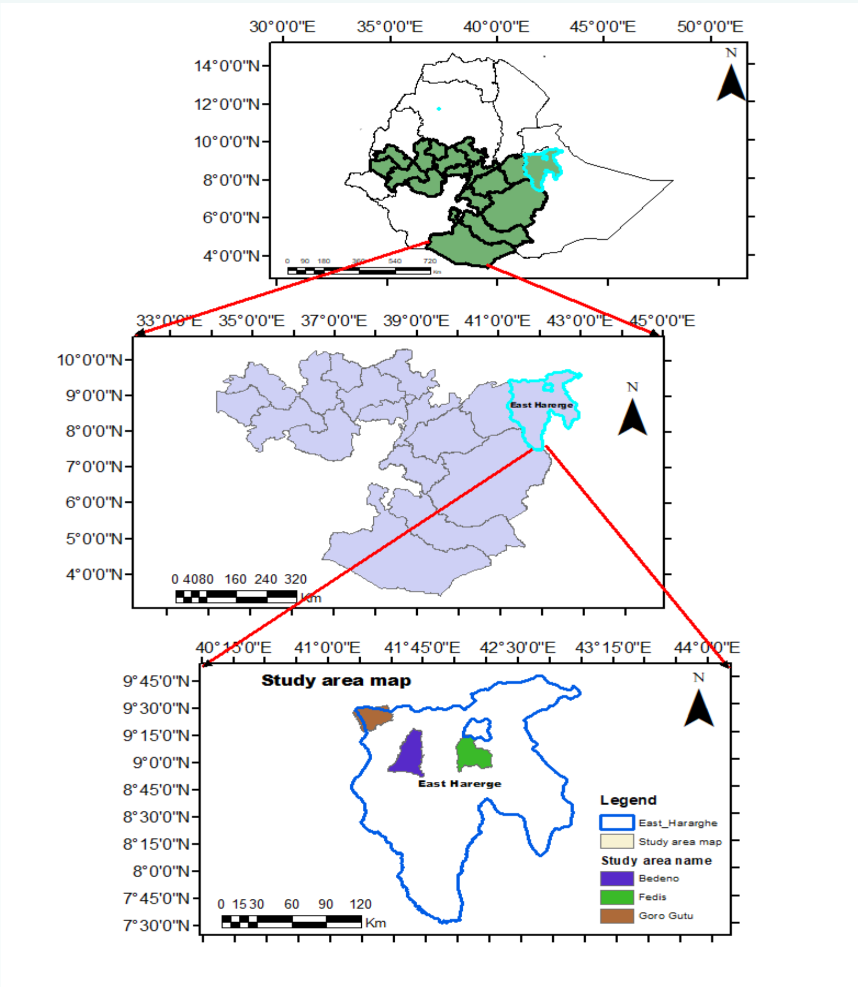

Figure 1 Map of the study area.

Statistical data analysis

SAS-program version 9.4 [16] was used for all statistical analyses in this study.

Exploratory data analysis

To get descriptive statistics and chi-squares tests, qualitative morphological traits were subjected to exploratory data analysis using the PROC FREQ procedures of SAS [16]. The data was analysed by contingency tables (Pearson's Chi-square) and when the cell counts were below five, they were analysed by Fisher's Exact Test method to establish a correlation between any two traits.

Multiple correspondence analysis

In trying to establish if there could be any correlation for more than two categorical traits, MCA was applied. MCA is a multivariate technique designed to discover both inter-relations and intra-relations of two or more categorical variables by reviewing the closeness and remoteness between them [17-19]. The MCA technique aims to show the group changes to rows and columns of categorical data arranged in the form of a contingency table in graphical form in a less-dimensional space [20]. This technique is very advantageous because it is easier to apply than such other alternatives as Chi-square analysis, G-test, Z-test, Fisher Exact test or Log-linear models, because it provides more detailed information to the researcher, and it can present the results in visual form [18,21,22]. Each of the trait levels reviewed through MCA is represented with a dot in a multi-dimensional space. Dots being close to each other are similar to or related to each other depending on the areas they fall into. Similarly, dots being far from each other are unrelated [23].

Results and Discussions

Exploratory data analysis

Descriptive statistics and chi-squares test results of the qualitative morphological traits with their statistical significance are presented in table 1. All the traits showed a wide range of variability (frequencies and percentages) between the districts.

The results of the study show that there are significant differences in the distribution of some qualitative morphological traits between the three districts (Bedeno, Fedis, and Gorogutu) while others do not show significant differences.

The analysis of Coat Colour Pattern (CCP) revealed that the p-value is 0.8762, indicating no significant difference in the distribution of CCP among the districts at a significance level of 0.05. The most prevalent CCP observed was plain, accounting for 18% in Bedeno, 16% in Fedis, and 17% in Gorogutu. The second most common CCP was patchy, representing 12% in Bedeno, 14% in Fedis, and 13% in Gorogutu. The least common CCP was spotted, accounting for 3% in Bedeno, Fedis, and Gorogutu. These findings align with previous studies conducted by [24], who also reported a majority of goats with plain CCP, and [25], whose study indicated that 54% of Abergelle goats had plain CCP.

Regarding Head Profile (HP), a significant difference was found in the distribution of concave, convex, and straight head profiles among the three districts ($p < 0.0001$). The most prevalent HP was straight, accounting for 24% in Bedeno, 15% in Fedis, and 14% in Gorogutu. The second most common HP was concave, representing 7% in Bedeno, 13% in Fedis, and 14% in Gorogutu. The least common HP was convex, accounting for 2% in Bedeno, 5% in Fedis, and Gorogutu.

In terms of horn presence, which is an essential self-defense mechanism for goats in harsh environments, the p-value was 0.6762, indicating no significant difference in the distribution of horn presence among the districts. The majority of goats possessed horns, with 23% in Bedeno and Gorogutu, and 25% in Fedis. This study contradicts an earlier report by [13] where 37% of goats were reported to be polled. Horns are considered an adaptive feature for fighting predators, particularly in tropical zones characterized by extensive production systems [26], where goats often compete for water and feed, even during mating. The percentage of goats without horns was lower, accounting for 10% in Bedeno and Gorogutu, and 9% in Fedis.

Regarding Horn Shape (HS), a significant difference was observed in the distribution of curved, spiral, and straight horn shapes among the three districts ($p = 0.0185$). The most common HS was straight, accounting for 22% in Bedeno, 20% in Fedis, and 23% in Gorogutu. The second most common HS was curved, representing 10% in Bedeno, 9% in Fedis, and 8% in Gorogutu. The least common HS was spiral, accounting for 1% in Bedeno, 5% in Fedis, and 3% in Gorogutu. A study conducted by [27] on Maefur goats reported that HS were predominantly straight (81%) and spiral (18%).

For Horn Orientation (HO), a significant difference was found in the distribution among the districts ($p = 0.0036$). The most prevalent HO was obliquely upward, representing 22% in Bedeno, 27% in Fedis, and 25% in Gorogutu. The second most common HO was backward for Bedeno and Gorogutu districts, accounting for 6% and 5%, respectively, and lateral for the Fedis district, accounting for 6%. The least common HO was lateral for Bedeno and Gorogutu districts, accounting for 5% and 3%, respectively, and backward for the Fedis district, accounting for 1%. In a study conducted by [27] on Maefur goats, HO was reported as backward (45%) and upright (41%)."

The distribution of Ear Orientation (EO) did not show a significant difference among the three districts ($p = 0.6521$). The majority of goats had erect ears, accounting for 30% in Bedeno and Fedis, and 29% in Gorogutu. The percentage of goats with pendulous ears was lower, with 3% in Bedeno, 4% in Fedis, and Gorogutu. However, a study by [24] reported that the majority of goats had horizontally oriented ears (81.9%) and long ears (93.1%), with lower proportions of semi-pendulous ear type (18.1%) and short ears (6.7%).

In terms of Back Profile (BP), no significant difference was found in its distribution among the districts ($p = 0.0796$). The most common back profile was straight, accounting for 26% in Bedeno, 21% in Fedis, and 23% in Gorogutu. The second most common profile was slope down from the wither, with percentages of 4% in Bedeno and 7% in Fedis and Gorogutu. The least common profile was slope up toward the rump, with percentages of 3% in Bedeno and Gorogutu, and 4% in Fedis.

The distribution of Horn Length (HL) did not show a significant difference among the districts ($p = 0.0704$). Small horn length was the most common, accounting for 29% in Bedeno, 26% in Fedis, and 27% in Gorogutu. The second most common length was medium, with percentages of 3% in Bedeno, 6% in Fedis, and 4% in Gorogutu. Large horn length was the least common, with percentages of 2% in Bedeno and Fedis, and 3% in Gorogutu.

There was a significant difference in the distribution of Hair Type (HT) among the three districts ($p = 0.0059$). The majority of goats had smooth hair type, accounting for 28% in Bedeno and 31% in Fedis and Gorogutu. The percentage of goats with glossy hair type was lower, with 5% in Bedeno and 2% in Fedis and Gorogutu. In contrast, [25] found that all observed goats had short and smooth hair. Smooth hair type is advantageous for heat dissipation and cleanliness, as opposed to curly and rough hair types that can harbor dirt and disease pathogens.

There were no significant differences in the distribution of wattle, beard, toggle, and muzzle pigmentation among the districts, with *p*-values of 0.3182, 0.5029, 0.3926, and 0.3926, respectively. However, there was a significant difference in the distribution of ruff presence among the districts, with a p-value of 0.0005. The majority of goats had a ruff present, accounting for 31% in Bedeno, 33% in Fedis, and Gorogutu. The

Table 1: Descriptive statistics and chi-squares test results of the qualitative morphological traits.

Characters and Attributes		District			ChiSquare	*p*-value
		Bedeno	Fedis	Gorogutu		
CCP	Patchy	54 (12.00)	63 (14.00)	60 (13.33)		
	Plain	81 (18.00)	73 (16.22)	75 (16.67)	1.211	0.8762
	Spotted	15 (3.33)	14 (3.11)	15 (3.33)		
HP	Concave	32 (7.11)	59 (13.11)	64 (14.22)		
	Convex	11 (2.44)	23 (5.11)	23 (5.11)	31.154	<0.0001
	Straight	107 (23.78)	68 (15.11)	63 (14.00)		
Horn	Absent	45 (10.00)	39 (8.67)	45 (10.00)	0.782	0.6762
	Present	105 (23.33)	111 (24.67)	105 (23.33)		
HS	Curved	32 (10.03)	29 (9.09)	24 (7.52)		
	Spiral	3 (0.94)	17 (5.33)	8 (2.51)	11.853	0.0185
	Straight	69 (21.63)	65 (20.38)	72 (22.57)		
HO	Backward	19 (5.90)	4 (1.24)	17 (5.28)		
	Lateral	16 (4.97)	20 (6.21)	9 (2.80)	15.605	0.0036
	Obliquely upward	70 (21.74)	88 (27.33)	79 (24.53)		
EO	Erect	136 (30.22)	133 (29.56)	131 (29.11)	0.855	0.6521
	Pendulous	14 (3.11)	17 (3.78)	19 (4.22)		
BP	Slope down from the wither	19 (4.22)	32 (7.11)	33 (7.33)		
	Slope up toward rump	14 (3.11)	20 (4.44)	12 (2.67)	8.349	0.0796
	Straight	117 (26.00)	98 (21.78)	105 (23.33)		
HL	Large	7 (1.56)	8 (1.78)	12 (2.67)		
	Medium	12 (2.67)	27 (6.00)	18 (4.00)	8.654	0.0704
	Small	131 (29.11)	115 (25.56)	120 (26.67)		
HT	Glossy	22 (4.89)	8 (1.78)	9 (2.00)	10.275	0.0059
	Smooth	128 (28.44)	142 (31.56)	141 (31.33)		
Wattle	Absent	129 (28.67)	136 (30.22)	128 (28.44)	2.290	0.3182
	Present	21 (4.67)	14 (3.11)	22 (4.89)		
Ruff	Absent	138 (30.67)	149 (33.11)	148 (32.89)	15.310	0.0005
	Present	12 (2.67)	1 (0.22)	2 (0.44)		
Beard	Absent	88 (19.56)	93 (20.67)	83 (18.44)	1.375	0.5029
	Present	62 (13.78)	57 (12.67)	67 (14.89)		
Toggle	Absent	133 (29.56)	127 (28.22)	125 (27.78)	1.870	0.3926
	Present	17 (3.78)	23 (5.11)	25 (5.56)		
Muzzle	Non-pigmented	133 (29.56)	127 (28.22)	125 (27.78)	1.870	0.3926
	Pigmented	17 (3.78)	23 (5.11)	25 (5.56)		
RP	Sloppy	144 (32.00)	142 (31.56)	145 (32.22)	0.769	0.6807
	Straight	6 (1.33)	8 (1.78)	5 (1.11)		

Values before brackets are frequencies while those in brackets are percentages; X^2 = Chi-Square; *Significant at $p < 0.05$; ns (not significant); CCP: Coat Colour Pattern; HP: Head Profile, horn, HS: Horn Shape; HO: Horn Orientation; EO: Ear Orientation; BP: Back Profile; HL: Hair Length; HT: Hair Type; wattles, ruff, beard, toggle, and RP: Rump Profile percentage of goats without a ruff was lower, with 3% in Bedeno, 0.2% in Fedis, and 0.4% in Gorogutu.

In all districts, the majority of goats had a beard present, with percentages of 14% in Bedeno, 13% in Fedis, and 18% in Gorogutu. The proportion of goats without a beard was 20% in Bedeno, 21% in Fedis, and 18% in Gorogutu. This finding contradicts an earlier report by [8]. Beardedness is a sex-influenced trait associated with reproductive functions.

The presence of toggle did not show a significant difference among the districts, with percentages of 30% in Bedeno, 29% in Fedis, and 28% in Gorogutu. The percentage of goats with a toggle present was lower, with percentages of 4% in Bedeno, 5% in Fedis, and 6% in Gorogutu.

The majority of goats in all districts had non-pigmented muzzles, with percentages of 30% in Bedeno, 29% in Fedis, and 28% in Gorogutu. The percentage of goats with pigmented muzzles was lower, with percentages of 4% in Bedeno, 5% in Fedis, and 6% in Gorogutu.

Regarding rump profile, the majority of goats in all districts had a sloppy rump profile, with percentages of 32% in Bedeno, Fedis, and Gorogutu. The percentage of goats with a straight rump profile was lowThe paragraph describes the distribution of various physical characteristics among goats in three districts (Bedeno, Fedis, and Gorogutu). The characteristics include ear orientation (erect or pendulous), back profile (straight, slope down, or slope up), horn length (small, medium, or large), hair type (smooth or glossy), and the presence of certain features such as ruff, beard, toggle, and pigmentation on the muzzle.

According to the paragraph, there were no significant differences in the distribution of ear orientation, back profile, and horn length among the districts. The most common ear orientation was erect, the most common back profile was straight, and the most common horn length was small.

However, there was a significant difference in the distribution of hair type among the districts. The majority of goats had smooth hair type, while a smaller percentage had glossy hair type. Smooth hair type is considered advantageous for heat dissipation and cleanliness.

The presence of certain features, such as ruff, beard, toggle, and pigmentation on the muzzle, did not show significant differences among the districts, except for the presence of a ruff. The majority of goats had a ruff present, and the percentage of goats without a ruff was lower.

It's worth noting that the paragraph refers to specific studies [8,24,25] for some comparisons and makes observations about how the findings may contradict or align with those studies.

The variations in the morphological traits especially coat colour pattern and hair type are reflections of the goats' adaptability to the various ecological zones they are raised, and also the vegetation and relief features of the ecological zones. The present results on the dominance of multiple coat colouration are in agreement with similar reports by [28] in Ghana goats. This provides an opportunity for a more effective breeding strategy to be adopted to select towards specific coat colour, as there is a relationship between polygenic effects of coat colour and other traits of interest (for example, physiology, morphology and behaviour).

Multivariate analysis

The eigenvalue measure indicates how much of the categorical information is accounted for by each dimension. The higher the eigenvalue, the larger the amount of the total variance among the traits on that dimension. Usually, the first two or three dimensions contain higher eigenvalues than others.

In table 2, eigenvalues and percentages of variance of the dimensions are revealed. It can also be seen that there is a steady decrease in eigenvalues. The first principal axis explained 15.19% of the principal inertia, the second principal axis explained 12.29%, and cumulatively the first two principal axes explained 27.5% of the principal inertia. In a similar study undertaken by [12,14] lower percentage (i.e., 17% and 16%) of the total variations were explained by the first two dimensions respectively.

Table 2: Eigenvalues, the percentages and cumulative percentages for all dimensions of the data matrix.

Eigen Value	% of Variance	ChiSquare	Per cent	Cumulative %
0.50729	0.25735	1079.8	15.19	15.19
0.45624	0.20815	873.3	12.29	27.48
0.41914	0.17568	737.1	10.37	37.84
0.36944	0.13648	572.6	8.06	45.90
0.36128	0.13053	547.6	7.70	53.60
0.35783	0.12804	537.2	7.56	61.16
0.35750	0.12781	536.2	7.54	68.71
0.34547	0.11935	500.7	7.04	75.75
0.34302	0.11766	493.7	6.95	82.70
0.34007	0.11565	485.2	6.83	89.52
0.30950	0.09579	401.9	5.65	95.18
0.28287	0.08002	335.7	4.72	99.90
0.03724	0.00139	5.8	0.08	99.98
0.01836	0.00034	1.4	0.02	100.00

Table 3 lists the significance of each of the attributes of the traits in both dimensions. The higher values of the partial contributions for a given trait indicate a higher association between the dimension and the trait. The top five dominant attributes of a trait in dimension 1 were hierarchically: pigmented muzzle, presence of toggle, non-pigmented muzzle, absence of toggle, and slope-up towards rumpback profile. For dimension 2, the corresponding values were: absence of horn, slope downward from the whither back profile, pendulous ear orientation, concave head profile, and presence of horn.

Table 3: Partial contributions to inertias (eigenvalues) for the first two dimensions.

Y	Category	Dimension 1	Category	Dimension 2
1	Pigmented-muzzle	0.35258	Absence of horn	0.19581
2	Presence of toggle	0.35258	Slope downward from the whither back profile	0.11680
3	Non-pigmented muzzle	0.05935	Pendulous ear orientation	0.10542
4	Absence of toggle	0.05935	Concave head profile	0.08883
5	Slope-up towards rump back profile	0.02720	Presence of horn	0.07056

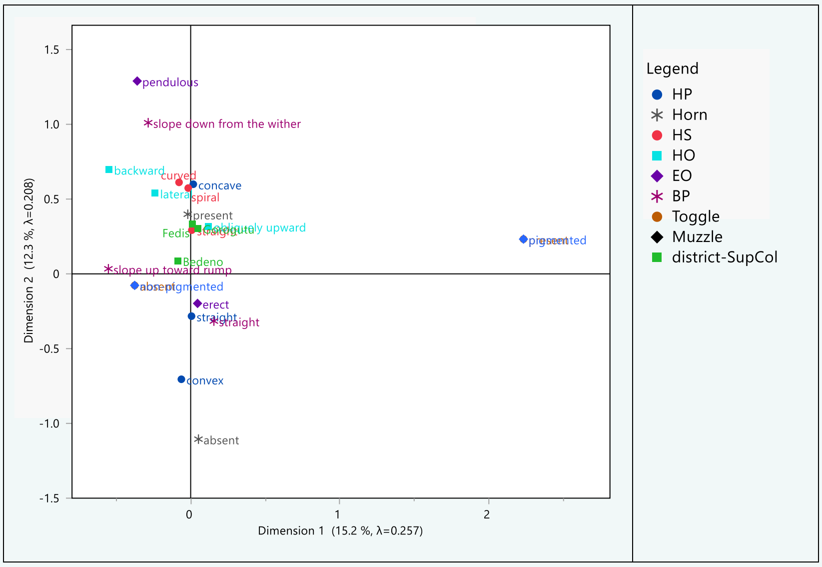

Figure 2 Two-dimensional biplot illustrating the association among qualitative morphological traits.
FD: Feather Distribution; SC: Shank Colour; ELC: Ear Lobe Colour; SkC: Skin Colour; CT: Comb Type; HSp: Hens Spurs; W&R: White and Red

The construction of the MCA plot involved a step-wise approach. Each group of traits underwent MCA analysis, and the squared cosine test was utilized to select traits. Traits with a $\cos^2 > 0.2$ value greater than 0.2 in at least one of the three primary MCA dimensions were retained. Figure 2 visually depicts the relationships among the analyzed trait categories in a two-dimensional graph. To explore the associations between districts and qualitative traits, the district variable was included as a supplementary variable in the analysis.

MCA, a graphical representation technique, aims to position highly correlated categories close to each other on the plot while separating uncorrelated ones. Categories that are close to the mean value are plotted near the origin of the MCA plot, while those that are more distant are plotted farther away. Therefore, the positions of points on the map, along with their loadings over the dimensions, serve as crucial indicators for interpreting the dimensions.

Based on the identified dimensions (Figure 2), the goat populations of Fedis and Gorogutu exhibited clustering with concave Head Profile (HP), straight Horn Shape (HS), obliquely upward Horn Orientation (HO), presence of a toggle, and pigmented muzzle. On the other hand, the goat population of Bedeno clustered together with traits such as the presence of horns, curved and spiral Horn Shape (HS), backward and lateral Horn Orientation (HO), and Ear Orientation (EO) in combination with a back profile that slopes down from the withers, slopes up toward the rump, and pendulous ears.

Conclusions

In conclusion, this study offers significant contributions to our understanding of the distribution of qualitative morphological traits within indigenous goat ecotypes across the districts of Bedeno, Fedis, and Gorogutu. The implementation of the MCA method enabled the identification of systematic relationships among traits and their attributes, providing a simplified interpretation of complex and extensive data. The strength of MCA in handling multidimensional data proved particularly valuable in exploring the factors influencing qualitative morphological traits. These findings enhance our knowledge of pattern recognition associated with these traits and highlight the potential for future research endeavours that encompass a broader range of traits and larger datasets.

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