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Morphometric Differentiation of Indigenous Tswana Goat Populations in Botswana Using Canonical Discriminant Analysis

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Abstract: Indigenous goats are renowned for their endurance and capacity to withstand extreme climatic conditions. To categorize indigenous animal genetic resources, morphometric measurements have been employed to analyze the properties of numerous farm animal populations and breeds. The purpose of this research was to use canonical discriminant analysis to categorize the diverse Tswana goat populations in Botswana based on their morphometric characteristics. A total of 1324 does were sampled from the five agroecological regions of Botswana. Only goats with Four Pairs of Permanent Incisors (4PPI = 48 months) were considered to minimize age effects. A hanging scale was used to measure body weight and other body parameters were measured using a fabric measuring tape. Data on morphometric traits were analyzed using the general linear model techniques of the statistical analysis system. The CANDISC algorithm was used to calculate Mahalanobis distances between class means, canonical variables, and eigenvalues. The largest Mahalanobis distance (8.79) was observed between the indigenous goat populations of Central and Ngamiland. The Southern and Gaborone goat populations had the smallest Mahalanobis distance (1.75). The analysis among the five agro-ecological regions identified CAN1 (93.4%) to be statistically significant ($p<0.001$). However, CAN1 and CAN2 together constituted 97.5% of all changes among the canonical variables, showing a thorough representation of most of the indigenous goats under the study. The morphological distance results confirm that the Ngamiland goat population was morphologically distinct from the other indigenous Tswana goat populations.

Keywords: Tswana Goat, Morphometric Traits, Canonical Discriminant Analysis, Mahalanobis

Introduction

Indigenous goats are known to be very resilient and adapt well to harsh climatic conditions. Even under the most challenging drought conditions, the goats thrive with limited and poor-quality feed resources. They are more prolific and have a shorter reproduction time (Dixit *et al*., 2010). Smallholder farmers depend heavily on goat production for meat, milk, manure, skins, cashmere from Kashmir goats, and mohair from Angora goats, as well as income (Haenlein and Ramirez, 2007). A report by Arandas *et al*. (2017); Valsalan *et al*. (2020) indicated that researchers have classified the genetic resources of indigenous animals and identified their origins by analyzing the traits of diverse farm animal populations and breeds using morphometric measurements. Analyzing variation in morphological features is the initial step in characterizing local animal genetic resources, according to Delgado *et al*. (2001).

Body parameters are crucial data sources for capturing breed standards and revealing details about the morphological makeup and developmental capacity of the animals (Riva *et al*., 2004). Canonical discriminant analysis has been reported as the best way to describe the connection between morphological structures, as stated by Legaz *et al*. (2011). When all morphological characteristics are analyzed together, as they are in canonical discriminant analysis, population types can be distinguished. As a result, it is useful in comprehending the diversity study and phenotypic association in a certain livestock population (Melesse *et al*., 2022). In the lack of background characterization data, some breed groups and their distinguishing features may dramatically diminish or vanish, which could delay the identification of their value and the implementation of conservation measures (Hoffmann *et al*., 2011).

According to Awobajo *et al*. (2015), livestock production in Sub-Saharan Africa is hampered by a lack of knowledge about indigenous genetic resources and how to use them sustainably. Information on genetic variability measurements and genetic differences of Tswana goat breeds in Botswana are very scanty, which delays proper utilization and conservation efforts. Characterizing indigenous animal genetic resources promotes the sustainable use of indigenous livestock, which are usually more productive than exotic breeds under low input levels. The objective of this study was to use canonical discriminant analysis to differentiate the various Indigenous Tswana goat populations in Botswana according to their morphometric traits.

Materials and Methods

Study Site

The data used was gathered from five different agroecological regions across Botswana: Ngamiland, Central, Kgalagadi, Southern, and Gaborone. The five agro-ecological regions generally experience a semi-arid climate, with high temperatures between September and April and low temperatures between May and August. Low, erratic, and unevenly distributed rainfall is experienced every year (Makhabu *et al*., 2002). The average annual rainfall in the country stands at 475 mm, comprised of isolated thunderstorms and showers (Statistics Botswana, 2020).

Sampling of Households

Five to ten villages were chosen from each region, and households within each village were chosen using a systematic random sampling procedure. The purposive sampling strategy for targeting traditionally recognized populations was complemented by systematic random sampling, which considered geographical isolation, ecological isolation, and clear phenotypic distinctness of populations. Only 1 to 4 animals per household were used for quantitative trait recording to avoid oversampling related goats. In total, 1324 were sampled across Botswana's five agroecological regions. The number of samples in each region were: Central = 517, Southern = 149, Gaborone = 224, Ngamiland = 272, and Kgalagadi = 162.

Data Collection

Dentition technique and owner information were used to determine the approximate ages of the animals. Only goats with Four Pairs of Permanent Incisors (4PPI = 48 months) were considered to minimize age effects. Body Weight (BW) was measured using a hanging scale, Body Length (BL), Horn Length (HL), Height at Withers (HW), Height at Rump (HR), Pelvic Width (PW), Chest Width (CW), Chest Girth (CG), and Ear Length (EL) were measured using a fabric measuring tape (recorded to the nearest cm) in accordance with FAO (2012) guidelines. To reduce the effects of feeding and watering, goats were sampled first thing in the morning. All measurements were taken on healthy non-pregnant goats.

Statistical Analysis

Data on morphometric traits were analyzed using the General Linear Model (GLM) techniques of the Statistical Analysis System (SAS, 2012). The magnitudes of the quantitative parameters were represented as least square means (±SE). The Chi-square test (χ^2) was used to assess the possibility of a statistically significant difference between the frequencies observed in two or more categories, with a level of significance set at 5%. To compare means between study regions or populations, the F test was used. To separate out the means, the Tukey-Kramer test was performed. This model was utilized for analyzing morphometric parameters:

$$Y_{ij} = \mu + A_i + e_{ij}$$

where,
Y_{ij} = Linear body measurements observations
μ = Population mean
A_i = Agroecological regions' fixed effect
e_{ij} = Normal distributed random error

The CANDISC algorithm was used to calculate Mahalanobis distances between class means, canonical variables, and eigenvalues. The first two canonical variables were used to generate a scatter plot in TEMPLATE and SGRENDER. To identify the morphological traits with the strongest discriminant power, stepwise discriminant analysis (PROC STEPDISC) in SAS was used. Finally, the DISCRIM technique was used to assess the proportion of goats that could be categorized into their original populations using quadratic discriminant analysis.

Results

The Mahalanobis distances estimated between the five agro-ecological regions are shown in Table 1. All pair-wise comparisons showed significant distances ($p<0.001$). Table 1, the Gaborone region goat population tends to be the closest to all other indigenous Tswana goat populations in Botswana. The greatest distance (8.79) was found between indigenous goat groups in Central and Ngamiland. The Southern and Gaborone goat populations had the smallest Mahalanobis distance (1.75).

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Table 1: Mahalanobis distances among the indigenous Tswana goat populations of the five agro-ecological regions based on morphometric traits

Agroecology	Central	Southern	Gaborone	Ngamiland	Kgalagadi
Central	0.00				
Southern	2.31	0.00			
Gaborone	3.64	1.75	0.00		
Ngamiland	8.79	6.99	5.55	0.00	
Kgalagadi	5.11	3.52	2.52	4.09	0

All distances are significant at $p<0.001$

Table 2: Summary of canonical discriminant analysis of morpho-structural variables of the indigenous Tswana goats

Function	Eigenvalue	% Variance	Cumulative %	Canonical Correlation
CAN1	11.318	93.4	93.4	0.959
CAN2	0.497	4.1	97.5	0.576
CAN3	0.220	1.8	99.4	0.425
CAN4	0.078	0.6	100.0	0.268

CAN1 = canonical variable 1; CAN2 = canonical variable 2; CAN3 = canonical variable 3; CAN4 = canonical variable 4

Two clusters are depicted in the dendrogram (Fig. 1). Cluster one consists of the Ngamiland goat population as a distinct, autonomous population, and cluster two consists of all other goat populations grouped into two subclusters, with the Central goat population grouped in one subcluster and those of Southern, Gaborone, and Kgalagadi in the second subcluster.

Table 2 reflects the canonical functions and correlations with eigenvalues for Tswana goats. The canonical discriminant analysis produced the first canonical correlation, a linear mix of variables having the highest multiple correlations with groups. Accordingly, the analysis among the five agro-ecological regions identified CAN1 (93.4%) to be statistically significant ($p<0.001$) and other nonsignificant canonical variables that accounted for 4.1, 1.8 and 0.6% of the overall variations. However, CAN1 and CAN2 together constituted 97.5% of all changes among the canonical variables, showing a thorough representation of most of the indigenous goats under the study. The eigenvalues for CAN1 and CAN2 were 11.318 and 0.497, respectively, and combined they constituted 97.5% of the total variance. The first two canonical variables are plotted in Fig. 2 to highlight the connections between the goat populations in various regions. The plot clearly showed that CAN1 discriminates the population of the Ngamiland region from those of the other regions. There is a visible overlap between the goat populations of four agro-ecologies of Central, Southern, Gaborone, and Kgalagadi, indicating the existence of a degree of homogeneity, as shown in the figure.

Standardized canonical coefficients help evaluate each original trait's contribution to each canonical variable (Table 3). In Tswana goats, the first canonical variable CAN1 loaded for body length (0.44), and CAN2 and CAN3 both loaded for body weight (0.48 and 0.51), respectively. Lastly, CAN4 loaded for head length (0.52). High canonical variable loadings indicate that these traits may be useful for discriminating indigenous Tswana goats across different agro-ecologies. The discriminant analysis presented further data (Table 4).

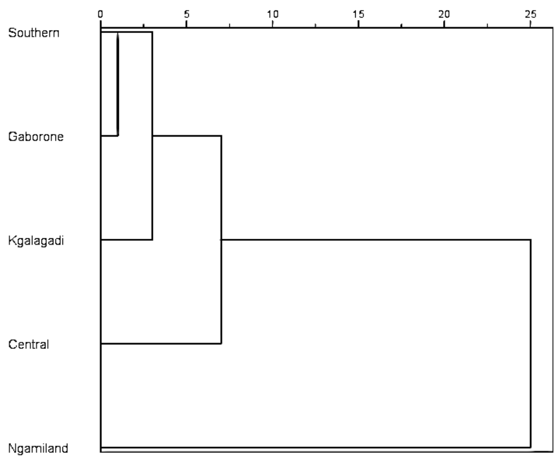

Fig. 1: Morphometric trait-based dendrogram of indigenous Tswana goat populations from five agro-ecological regions

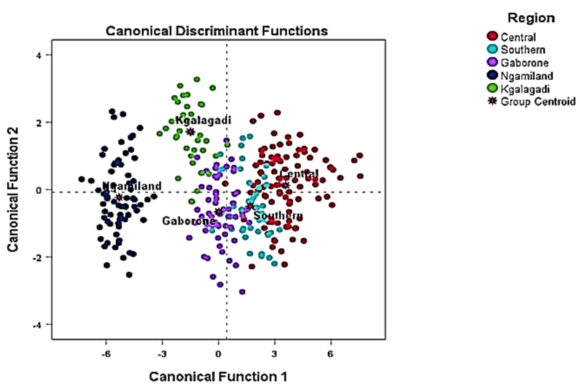

Fig. 2: Canonical illustration of the Tswana goat populations of the five agro-ecological regions based on morphometric traits

Table 3: Standardized total canonical structure of morpho-structural variables of the indigenous Tswana goats

Variables	CAN1	CAN2	CAN3	CAN4
Body length	0.44	-0.45	-0.12	-0.24
Height at withers	0.13	0.40	0.34	-0.11
Chest girth	0.40	0.25	-0.78	0.10
Height at rump	0.24	-0.12	0.26	0.40
Pelvic width	0.30	-0.40	0.14	-0.34
Head length	0.20	-0.32	0.32	0.52
Shin circumference	0.16	0.48	-0.15	0.26
Body weight	0.18	0.48	0.51	-0.54

Table 4: Percent (%) of the individual goats classified into their respective agro-ecological regions based on morphometric variables

Agroecology	Central	Southern	Gaborone	Ngamiland	Kgalagadi
Central	85.61	8.16	4.00	0.60	1.63
Southern	20.90	64.67	14.00	0.00	0.43
Gaborone	6.00	10.00	82.30	0.00	1.70
Ngamiland	0.10	0.00	0.00	99.48	0.42
Kgalagadi	2.82	2.70	10.80	0.10	83.58

The populations in the Central, Gaborone, Ngamiland, and Kgalagadi regions were classified into their source population (85.61, 82.30, 99.48 and 83.58%), whilst 20.90% of does in the Southern region population were classified as Central region individuals.

Discussion

The linear body and physical measurements of goats provide a wealth of information on performance aspects such as kidding efficiency, lactation length, and milk and meat production. There is currently more focus on characterizing African native animal genetic resources (Yakubu *et al*., 2009). The results of this study reveal some distinct morphological variations between and among populations of Tswana goats across Botswana's diverse regions. However, there are various goat ecotypes associated with different agroecological regions. The observed variation in morphometric traits may be caused by differences in genetic makeup, as well as climatic factors and husbandry practices (Nguluma *et al*., 2016). The Southern and Gaborone goat populations have the lowest Mahalanobis distance (1.75), indicating genetic homogeneity. Migration over decades may have induced non-selection, ongoing inbreeding, and admixture occurrences (Melesse *et al*., 2022). The largest distance was found between the indigenous goat populations of Central and Ngamiland, indicating less homogeneity between the two populations. Arandas *et al*. (2017); Dekhili *et al*. (2013) found similar evidence of a greater distance between indigenous goat populations in Algeria and Brazil, respectively. The morphological distance results confirm that the Ngamiland goat population was morphologically distinct from the other indigenous Tswana goat populations. Assessing morphological distances could assist to gain insight into the genetic diversity of indigenous animal populations and enable the creation of appropriate breeding strategies to conserve animal genetic resources.

The canonical analysis identified the morphological traits that contributed most to quantifying the variation among the goat populations. In this study, a canonical variable (CAN1) was found to account for about 93.4% of the total variation attributable to a canonical evaluation based on morphometric parameters. These results are in line with those of Selolo *et al*. (2015), who observed that for indigenous goats in South Africa, the first canonical variable constituted 91.9% of the overall variation. According to Ogah (2013), the overall variance in chickens was reported to be 59.7 and 40.3% (CAN1 and CAN2), respectively. Melesse *et al*. (2002) found that changes in production conditions, genetic diversity, and the physical features studied could all account for the observed differences across every canonical element in the body of literature. According to Yakubu *et al*. (2010), an overall 100% of Red Sokoto goats along with 99.4% of West African Dwarf (WAD) goats were successfully allocated to their respective source groups in Nigeria, resulting in a success rate of 99.7%.

Conclusion

This study discovered that morphometric traits could successfully differentiate the five indigenous Tswana goat groups. The Ngamiland goat population was found to be distinct from the other four populations using canonical discriminant analysis. All goats were properly matched to their originating groups, demonstrating morphological uniformity in the groups. The goat population in the five regions could be classified into distinct populations using the multivariate analysis of morphometric traits as the criterion for differentiation. Therefore, any of the five indigenous goat populations could leverage the observed morphometric features in their breeding programs for increased efficiency and financial benefits.

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Ethics

North-West University's Animal Production Sciences Research Ethics Committee reviewed and accepted the study's ethical standards (reference: NWU-00877-19-A5).

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