American Journal of Animal and Veterinary Sciences

Original Research Paper

On-Farm Phenotypic Characterization of Sheep Breeds in Botswana

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Article history
Received: 24-06-2024
Revised: 20-08-2024
Accepted: 04-10-2024

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Abstract: Phenotypic characterization data serve as a baseline for the evaluation of the effectiveness of selection programs and the development of conservation strategies. Therefore, this study aimed to phenotypically characterize Tswana, Dorper, Damara, Meat-master, and Karakul sheep breeds in Botswana under a ranch management system. Qualitative and quantitative data was collected from 595 adult sheep (one year and above). Data on qualitative and quantitative traits were analyzed by employing the frequency and General Linear Model (GLM) procedures of Statistical Analysis System (SAS) 9.4, respectively. Damara and Meat-master sheep had brown coat color and straight long tails. Dorper and Karakul breeds had plain coats, with Dorper having a black head and white body while Karakul was entirely black. Tswana sheep exhibited a patchy white coat pattern. Breed and sex significantly influenced body weight and most linear body measurements, with males generally being heavier than females. Meat-master, Dorper, and Karakul rams had significantly higher body length, heart girth, head width, and ear width than their indigenous counterparts (Tswana and Damara). There were no significant differences between Damara and Tswana rams in body weight, heart girth, ear width, and rump width. Dorper ewes had significantly higher body length, shoulder width, and rump width. Body weight, heart girth, and height at withers were significantly higher in Damara and Meat-master castrates. The study indicated variation across sheep breeds in Botswana under a ranch management system, which may aid in breed improvement programs.

Keywords: Body Weight, Coat Color, Ranch-Managed, Sex, Traits

Introduction

Sheep plays an essential role in the socio-economic and socio-cultural livelihoods of people living in rural areas (Aganga and Aganga, 2015; Sako *et al*., 2024). Sheep are a source of meat which provides food security to farmers. The sheep population in Botswana is estimated to be 227 247, and the indigenous Tswana sheep constitute the majority (about 58%) of this national flock (Statistics Botswana, 2016). Tswana sheep are more adapted to the harsh environmental conditions of Botswana, are tolerant to prevalent local diseases and parasites, and are able to utilize limited poor feed resources (Nsoso *et al*., 2004). However, Tswana sheep lack traits of economic importance, such as meat production, which are highly embedded in exotic breeds. As a result, farmers have introduced exotic breeds in an endeavor to improve meat production by crossbreeding the indigenous Tswana with their exotic counterparts (Bolowe *et al*., 2022). Today, other prominent sheep breeds now found in Botswana harboring economically important traits, in particular meat production, include the Dorper, Damara, Meat-master, and the Karakul. Their introduction in Botswana necessitates the development of long-term strategies and policies that will govern the proper conservation, breeding, and responsible management of such vital Animal Genetic Resources (AGR) in the country. The precondition to the formulation of improvement, conservation, and utilization strategies and policies for these AnGRs to sustainably meet future market demands is their characterization. Breed characterization is important as it informs researchers, policymakers and conservationists on the status of animal genetic resources (Edea *et al*., 2017). The absence of adequate characterization data potentially leads to missing conservation decisions, genetic erosion, and replacement/dilution of breeds with unique traits (Kunene *et al*., 2009).

Phenotypic characterization entails the detailed description of the appearance, production, and adaptive traits of AnGR, together with the interactions and complexities of the environmental factors in which they are found (Becker and Fourie, 2021). Several studies on phenotypic characterization of Dorper (Mohammed *et al*., 2018; Selala and Tyasi, 2022) Karakul (Musavi *et al*., 2022) and Meat-master sheep (Becker and Fourie, 2021) have been done in areas like Ethiopia, South Africa, North Afghanistan, but none has been done in the local Botswana environment. Studies on the Damara sheep have only focused on the production and adaptive traits of the breed, and to a limited extent, its linear body measurements (Almeida, 2011; Kandiwa *et al*., 2019; Ngcobo *et al*., 2022). In the context of the indigenous Tswana sheep, phenotypic characterization studies of the breed exist (Nsoso *et al*., 2004; Bolowe *et al*., 2021), but were carried out under extensively managed animals. This may not give a precise reflection of what is happening to the morphology of the sheep under ranch management systems as they may be experiencing alternative levels of evolutionary dynamics such as selection and random genetic drift, to name but a few. Given that, sheep in the ranch management system may lose or gain certain morphological traits that make them distinct from those managed extensively. It is therefore important to characterize all the sheep breeds found in Botswana to monitor their performance under the local Botswana environment and to account for the changes that may be caused by evolutionary forces across different environmental and management conditions. The information will help policymakers formulate improvement, conservation, and utilization strategies to meet future market demands sustainably. Therefore, this study aimed to phenotypically characterize the Tswana, Dorper, Karakul, Meat-master, and Damara sheep breeds under the ranch management system.

Materials and Methods

Study Site

The study was conducted between March and June 2023 at the Lobu field station and the Botswana University of Agriculture and Natural Resources (BUAN) research farm. BUAN Farm is in Botswana's Southeast region, which has a semi-arid climate. The Lobu field station is situated in the Kgalagadi South district in the southwest of Botswana (26°35’13’S 21°49’02’E), approximately 110 km from Tsabong village and 10 km from the nearby village of Khuis. The Kgalagadi area has minimal summer rainfall, averaging roughly 300 mm per year. Summer temperatures normally range from 29-35°C, whereas winter temperatures fall to 1-12°C (Seifu *et al*., 2019). This region is well-known for having one of the longest dry seasons, which can last up to six months (from April to October). The research site has an arid savannah woodland and grassland habitat with limited vegetation and a range of grass species (Kgaudi *et al*., 2018).

Management of the Animals

The animals were kept in open kraals made from treated gum poles and diamond wire for easy ventilation. The kraals had shade, feeding, and drinking troughs for hot temperatures. The animals were allowed to graze freely in the ranch during the day and supplemented with lucerne and commercial feed (Small-stock grower) when they came back in the kraals later in the day. The animals slept in the kraals to protect them from predators. There were no bird and rodent-proof measures put in place. The animals were routinely dewormed and vaccinated against diseases.

Data Collection

Qualitative attributes were evaluated visually, while quantitative traits were documented from a sample of 595 sheep, comprising Tswana, Dorper, Damara, Meat-master, and Karakul breeds, using the FAO (2012) morphological characteristics descriptor guide for phenotypic characterization. The qualitative traits studied included coat color, coat form, presence or absence of horns and wattles, horn shape, ear orientation, tail type, and tail form. A flexible measuring tape was used to evaluate the quantitative features: Body Length (BL), Heart Girth (HG), Height at Withers (HW), Shoulder Width (SW), Rump Height (RH), Rump Width (RW), Tail Length (TL), Tail Circumference (TC), Head Length (HL), Head Width (HDW), Neck Length (NL), Horn Length (HNL), Ear Length (EL), Ear Width (EW), Canon Bone Length (CBL), Canon Bone Circumference (CBC) and Scrotal Circumference (SC) in males. A weighing band was utilized to measure the Body Weight (BW) of the sheep in the sample. To minimize the influence of drinking and feeding on the animals' size, all measures were taken prior to eating, with the animals kept upright and given time to relax, in order to reduce the impact of drinking and feeding on the animals' size.

Statistical Analysis

Data on qualitative traits and quantitative linear body measurements was analyzed using frequency procedures and General Linear Model (GLM) procedures of Statistical Analysis System (SAS) 9.4, respectively. GLM procedures were used to determine least square means and standard errors of body weight and all other morphometric traits. The means were declared significant at $p \leq 0.05$. Breed and sex were treated as independent variables, whereas body weight and linear body measurements (excluding scrotal circumference) were considered as dependent variables. The scrotal circumference in rams was treated as a dependent variable and breed as an independent variable. The quantitative characteristics of the sampled sheep populations were analyzed using the models listed below.

Model for mean square analysis of body weight and linear body measurements:

$$Yij = \mu + Bi + Sj + (BxS)ij + eij$$

where:

Yij = Body weight and measured linear body measurements
μ = General population mean
Bi = *ith* breed effect
Sj = *jth* sex effect
(*BxS*)*ij* = Interaction effect of breed and sex
eij = Random error

Model for mean square analysis of scrotal circumference:

$$Yi = \mu + Bi + ei$$

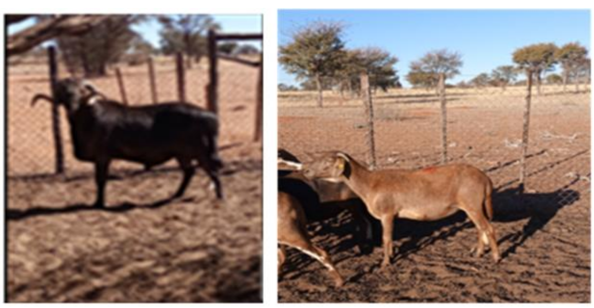
where:

Yi = Measured scrotal circumference
μ = General population mean
Bi = *ith* breed effect
ei = Random error

Results

Qualitative Traits of Different Sheep Breeds

The distribution of phenotypes in qualitative traits in different sheep breeds found in Botswana (%) is presented in Table (1). Most sheep in the different sheep breeds predominantly had a plain coat color pattern except for Tswana sheep, which had predominantly a patchy coat color pattern. Tswana sheep were predominately white, while most Karakul sheep were predominantly black. Brown coat color was more common in Damara and Meat-master sheep breeds, while the predominant coat color for Dorper was the white body with a black head. Damara and Meat-master breeds had tails that can be characterized as long-fat with straight tips and moderate with straight tips (Fig. 1), respectively. Other breeds were docked. All Damaras and Meat-masters sheep had semi-pendulous ears, and a high proportion of Tswana sheep also had semi-pendulous ears. Karakul sheep mostly had pendulous ears, while all Dorper sheep had horizontally oriented ears. All the breeds were polled except for the Damara and Karakul breeds. Damara sheep had a predominantly spiral horn shape, followed by a curved horn.



(a)

(b)

(c)

(d)

(e)

Fig. 1: (a) Damara ram and ewe; (b) Dorper ram and ewe; (c) Meat master ram and ewe; (d) Karakul ram and ewe; (e) Tswana ram and ewe

DOI: 10.3844/ajavsp.2025.53.63

Table 1: Percentage values for qualitative traits of different sheep breeds

Trait	Damara (%)	Dorper (%)	Karakul (%)	Meat-master (%)	Tswana (%)
Coat color pattern					
Plain	66.7	96.6	100	64.1	14.6
Patchy	NR	NR	NR	12.8	66.7
Spotted	33.3	3.4	NR	23.1	18.8
Coat color type					
White	NR	NR	NR	1.3	14.6
Black	11.9	NR	70.4	0.6	NR
Brown	54.8	NR	NR	61.5	NR
White body, black head	NR	96.6	2.22	NR	NR
Grey body, black head	NR	NR	27.4	NR	NR
White dominant	4.76	3.4	NR	16	79.2
Black dominant	2.38	NR	NR	2.6	4.2
Brown dominant	26.2	NR	NR	17.3	2.1
Hair type					
Short and smooth	100	100	NR	100	16.7
Long and smooth	NR	NR	99.3	NR	NR
Long and coarse	NR	NR	0.74	NR	6.3
Short and coarse	NR	NR	NR	NR	75
Tail type					
Short fat	NR	NR	6.7	NR	4.2
Long fat	100	NR	NR	NR	NR
Short thin	NR	NR	NR	NR	4.2
Long thin	NR	NR	NR	NR	NR
Long moderate	NR	NR	NR	100	NR
Docked	NR	100	93.3	NR	91.7
Tail form					
Curved at tip	NR	NR	NR	NR	NR
Straight at tip	100	NR	6.7	100	8.3
Docked	NR	100	93.3	NR	91.7
Ear form					
Horizontal	NR	100	NR	NR	20.8
Semi-pendulous	100	NR	6.7	100	68.8
Pendulous	NR	NR	93.3	NR	10.4
Erect	NR	NR	NR	NR	NR
Wattle					
Present	NR	NR	NR	NR	NR
Absent	100	100	100	100	100
Horn					
Present	73.8	NR	5.2	1.3	6.3
Absent	26.2	100	94.8	98.7	93.7
Horn shape					
Straight	NR	NR	1.5	NR	2.1
Curved	21.4	NR	3	1.3	2.1
Spiral	52.4	NR	0.7	NR	NR
Scurs	NR	NR	NR	NR	2.1

NR = Not Recorded

Effects of Sex on Quantitative Traits within Breeds

The influence of sex on body weight and linear body measurements in the different sheep breeds are presented in Table (2). There was a significant sex effect ($p<0.05$) on body weight and most linear body measurements in the different sheep breeds found in Botswana. BW, HG, TC, and RH of Damara castrates were significantly higher than that of rams and ewes. BW, HG, RH, RW, SW, HDW, and CBL for Dorper, Karakul, and Meat-master sheep breeds were significantly higher in rams than their female counterparts. There were no significant differences in BW, HG, HDW, CBC, or CBL between the ewes and castrates of Dorper and Karakul sheep. However, Damara and Meat-master sheep breeds had significantly higher HW and RW in males (Rams and castrates) than ewes. Damara ewes had significantly ($p<0.05$) higher HL, EL, NL, and TL than rams. There were no significant sex differences in BL, SW, EW, and CBL between Damara males and females. Tswana sheep also had similar BW and most linear body measurements between males and females except for RH, TL, and TC, which were significantly higher in males than females.

Table 2: Effect of sex on quantitative traits of different sheep breeds

Trait	Damara			Dorper			Karakul			Meat-master			Tswana		
	Rams	Ewes	Castrates	Rams	Ewes	Castrates	Rams	Ewes	Castrates	Rams	Ewes	Castrates	Rams	Ewes	Castrates
BW (kg)	55.5±1.98^{b}	51.7±1.72^{b}	80.5±8.06^{a}	68.9±1.52a	59.0±1.12b	58.9±2.85b	70.2±4.65^{a}	52.4±1.02^{b}	51.3±6.58^{b}	73.8±1.60^{a}	57.5±1.15^{b}	71.0±4.31^{a}	49.3±5.70	39.2±1.98	40.8±3.44
BL (cm)	68.9±1.01	68.1±0.88	73.0±4.11	77.1±0.78	75.6±0.57	74.4±1.45	76.3±2.37	72.0±0.52	70.3±3.36	79.2±0.81^{a}	71.8±0.59^{b}	80.3±2.20^{a}	61.3±2.91	56.5±1.01	55.5±1.75
HG (cm)	87.2±1.28^{b}	83.6±1.11^{c}	102.5±5.22^{a}	96.4±0.99a	87.3±0.72b	88.1±1.84^{b}	97.8±3.01^{a}	88.6±0.66^{b}	82.3±4.26^{b}	95.9±1.03^{a}	87.4±0.75^{b}	93.4±2.79^{a}	82.0±3.69	74.9±1.28	75.9±2.22
HW (cm)	74.3±0.75^{a}	71.5±0.65^{b}	79.5±3.07^{a}	68.1±0.58a	64.2±0.42b	66.6±1.08^{a}	75.3±1.77^{a}	66.4±0.39^{b}	69.3±2.50^{b}	75.0±0.61^{a}	69.8±0.44^{b}	75.0±1.64^{a}	66.0±2.17	63.0±0.75	64.3±1.31
SW (cm)	22.9±0.59	21.7±0.51	24.5±2.41	29.6±0.45a	25.0±0.33c	27.0±0.85^{b}	29.2±1.39^{a}	25.7±0.30^{b}	25.0±1.96^{b}	31.6±0.48^{a}	23.6±0.34^{c}	28.1±1.29^{b}	18.8±1.70	17.3±0.59	18.8±1.03
RH (cm)	74.1±0.68^{b}	73.1±0.59^{b}	81.5±2.76^{a}	66.8±0.52a	63.3±0.38b	65.3±0.98^{ab}	74.2±1.59^{a}	65.7±0.35^{b}	69.0±2.25^{ab}	73.2±0.55^{a}	70.1±0.39^{b}	73.6±1.48^{a}	66.4±1.95^{a}	62.0±0.68^{b}	63.5±1.18^{ab}
RW (cm)	20.5±0.41^{a}	18.6±0.36^{b}	23.5±1.67^{a}	25.3±0.32^{a}	24.0±0.23^{b}	24.1±0.59^{ab}	25.7±0.97^{a}	23.1±0.21b	21.7±1.36^{b}	23.9±0.33^{a}	22.7±0.24^{b}	24.9±0.89^{a}	18.5±1.18	17.0±0.41	17.2±0.71
HL (cm)	18.1±0.40^{b}	19.5±0.34^{a}	20.0±1.61^{a}	20.6±0.30^{a}	18.8±0.22^{b}	19.2±0.57^{b}	17.8±0.93	18.2±0.20	19.0±1.32	23.5±0.32^{a}	19.2±0.23^{b}	20.6±0.86^{b}	18.1±1.14	16.2±0.40	15.9±0.69
HDW (cm)	12.5±0.21a	10.5±0.18^{b}	12.5±0.86^{a}	13.9±0.16^{a}	11.3±0.11^{b}	11.7±0.30^{b}	14.8±0.50^{a}	12.1±0.11^{b}	11.3±0.70^{b}	13.9±0.17^{a}	11.7±0.12^{c}	12.9±0.46^{b}	9.6±0.61	8.7±0.21	8.6±0.37
HNL (cm)	29.8±1.71^{a}	7.9±1.79^{b}	12.3±6.93^{b}	NR	NR	NR	52.7±5.66^{a}	11.0±6.93^{b}	14.8±6.93^{b}	NR	NR	NR	NR	NR	NR
NL (cm)	25.7±0.97^{b}	28.3±0.84^{a}	24.0±3.94^{ab}	30.9±0.74^{a}	28.5±0.54^{b}	28.1±1.39^{ab}	27.2±2.27	27.7±0.50	28.0±3.22	39.5±0.78^{a}	26.3±0.56^{c}	31.6±2.11^{b}	20.3±2.79	19.6±0.97	19.1±1.68
EL (cm)	11.6±0.27^{b}	13.3±0.24^{a}	13.5±1.11^{a}	12.2±0.21	12.4±0.15	11.9±0.39	12.3±0.64	13.3±0.14	13.7±0.91	14.5±0.22^{a}	12.7±0.16^{b}	13.1±0.59^{b}	11.3±0.79	11.5±0.27	11.7±0.47
EW (cm)	6.3±0.12	6.6±0.10	6.8±0.48	7.1±0.09^{a}	6.3±0.07^{b}	6.3±0.17^{b}	7.5±0.28^{b}	7.6±0.06^{a}	6.3±0.39^{c}	7.2±0.10^{a}	6.9±0.07^{b}	7.0±0.26^{ab}	5.9±0.34	6.0±0.12	6.0±0.20
TL (cm)	55.1±1.30^{b}	51.0±1.13^{a}	56.0±5.29^{ab}	NR	NR	NR	NR	NR	NR	44.5±1.05^{a}	40.3±0.76^{b}	43.4±2.83^{ab}	42.0±7.48^{a}	28.0±7.48^{ab}	19.0±7.48^{b}
TC (cm)	20.4±0.71^{b}	17.0±0.62^{c}	26.9±2.90^{a}	NR	NR	NR	NR	NR	NR	19.5±0.57^{a}	12.9±0.41^{b}	20.0±1.55^{a}	23.5±4.10^{ab}	12.5±4.10^{b}	31.5±4.10^{a}
CBC (cm)	7.8±1.18^{a}	6.7±0.15^{b}	8.5±0.73^{a}	9.2±0.14^{a}	7.9±0.10^{b}	8.2±0.26^{b}	9.2±0.42^{a}	7.4±0.09^{b}	6.7±0.59^{b}	7.7±0.14	7.7±0.10	8.4±0.39	7.6±0.51	6.7±0.18	7.2±0.31
CBL (cm)	15.4±0.31	15.1±0.27	17.5±1.25	15.1±0.24^{a}	13.3±0.17^{b}	13.6±0.44^{b}	15.5±0.72^{a}	14.0±0.16^{b}	13.3±1.02^{b}	17.9±0.25^{a}	15.1±0.18^{b}	16.6±0.67^{a}	12.3±0.89	11.0±0.31	11.6±0.53
SC (cm)	24.1±0.66	NR	NR	27.5±0.51	NR	NR	25.8±1.55	NR	NR	25.6±0.53	NR	NR	21.5±1.90	NR	NR

[a,b,c] Means with different superscript within a breed are significantly different ($p<0.05$), NR = Not Recorded, BW = Body Weight, BL = Body Length, HG = Heart Girth, HW = Height at Withers, SW = Shoulder Width, RH = Rump Height, RW = Rump Width, HL = Head Length, HDW = Head Width, HNL = Horn Length, NL = Neck Length, EL = Ear Length, EW = Ear Width, TL = Tail Length, TC = Tail Circumference, CBC = Cannon Bone Circumference, CBL = Cannon Bone Length, SC = Scrotal Circumference

Effects of Breed on Live Body Weight and Linear Body Measurements of Rams

Rams across the different sheep breeds varied significantly ($p<0.05$) in BW and most linear body measurements except TC (Table 3). Meat-master, Dorper, and Karakul rams exhibited significantly ($p<0.05$) higher BL, HDW, HG, and EW than their indigenous (Tswana and Damara) counterparts. Damara rams had significantly ($p<0.05$) higher BL, SW, and HDW than Tswana rams, but the two breeds had similar BW, HG, EW, and RW. Meat-master rams had significantly ($p<0.05$) higher BW, NL, and SW than Dorper, Damara, and Tswana rams. There were no significant differences in BW and SW between Meat-master and Karakul rams. Significantly lower CBC was found in Damara, Meat-master, and Tswana rams than Dorper and Karakul rams, which both had a CBC of 9.2 cm. Dorper rams had significantly ($p<0.05$) the largest scrotal circumference, followed by Karakul, Meat-master, Damara, and lastly, Tswana rams.

Effects of Breed on Live Body Weight and Linear Body Measurements of Ewes

Ewes across the different sheep breeds ($p<0.05$) varied significantly in BW and most linear body measurements except HNL (Table 4). Dorper and Meat-master ewes were significantly ($p<0.05$) the heaviest breeds, followed by Karakul and Damara and lastly, Tswana sheep. Dorper ewes had significantly ($p<0.05$) higher BL, SW, and RW than their age-matched counterparts of other breeds in the study. However, there were no significant differences in HG between Dorper, Karakul, and Meat-master ewes. The BW of Damara and Karakul ewes were similar but significantly ($p<0.05$) higher than those of Tswana ewes. Damara ewes had significantly ($p<0.05$) higher HW, RH, HDW, HL, EL, NL, TL, TC, and CBL than other breeds in the study. Tswana and Damara's ewes had similar and significantly ($p<0.05$) lower CBC than their exotic counterparts.

Effects of Breed on Live Body Weight and Linear Body Measurements of Castrates

Castrates across the different sheep breeds significantly ($p<0.05$) varied in BW and most linear body measurements except in HNL and EL (Table 5). Damara and Meat-master castrate had significantly ($p<0.05$) higher BW, HG, CBL, and HW than castrates of other breeds in the study. Meat-master castrates had significantly ($p<0.05$) higher BL, HDW, and EW than castrates of the other four breeds. The Dorper, Karakul, and Damara castrate had similar BL, HDW, and EW, which were significantly higher than those of the

Tswana castrates. Similarly, there were no significant differences between the Dorper, Damara, Karakul, and Meat master castrates in SW, RW, and HL. Damara castrates had the longest tails, followed by Meat-master, while Tswana castrates had the shortest tails. However, the TC of Tswana and Damara castrates were similar.

Table 3: Morphological traits of rams across different sheep breeds

Trait	Damara	Dorper	Karakul	Meat-master	Tswana
BW (kg)	55.5±1.98^{c}	68.9±1.52^{b}	70.2±4.65^{ab}	73.8±1.60^{a}	49.3±5.70^{c}
BL (cm)	68.9±1.01^{b}	77.1±0.78^{a}	76.3±2.37^{a}	79.2±0.81^{a}	61.3±2.91^{c}
HG (cm)	87.2±1.28^{b}	96.4±0.99^{a}	97.8±3.01^{a}	95.9±1.03^{a}	82.0±3.69^{b}
HW (cm)	74.3±0.75^{a}	68.1±0.58^{b}	75.3±1.77^{a}	75.0±0.61^{a}	66.0±2.17^{b}
SW (cm)	22.9±0.59^{c}	29.6±0.45^{b}	29.2±1.39^{ab}	31.6±0.48^{a}	18.8±1.70^{d}
RH (cm)	74.1±0.68^{a}	66.8±0.52^{b}	74.2±1.59^{a}	73.2±0.55^{a}	66.4±1.95^{b}
RW (cm)	20.5±0.41^{c}	25.3±0.32^{a}	25.7±0.97^{ab}	23.9±0.33^{b}	18.5±1.18^{c}
HL (cm)	18.1±0.40^{c}	20.6±0.30^{b}	17.8±0.93^{c}	23.5±0.32^{a}	18.1±1.14^{c}
HDW (cm)	12.5±0.21^{b}	13.9±0.16^{a}	14.8±0.50^{a}	13.9±0.17^{a}	9.6±0.61^{c}
HNL (cm)	29.8±1.71^{b}	NR	52.7±5.66^{a}	NR	NR
NL (cm)	25.7±0.97^{cd}	30.9±0.74^{b}	27.2±2.27^{bc}	39.5±0.78^{a}	20.3±2.79^{d}
EL (cm)	11.6±0.27^{b}	12.2±0.21^{b}	12.3±0.64^{b}	14.5±0.22^{a}	11.3±0.79^{b}
EW (cm)	6.3±0.12^{b}	7.1±0.09^{a}	7.5±0.28^{a}	7.2±0.10^{a}	5.9±0.34^{b}
TL (cm)	55.1±1.30^{a}	NR	NR	44.5±1.05^{b}	42.0±7.48^{b}
TC (cm)	20.4±0.71	NR	NR	19.5±0.57	23.5±4.10
CBC (cm)	7.8±1.18^{b}	9.2±0.14^{a}	9.2±0.42^{a}	7.7±0.14^{b}	7.6±0.51^{b}
CBL (cm)	15.4±0.31^{b}	15.1±0.24^{b}	15.5±0.72^{b}	17.9±0.25^{a}	12.3±0.89^{c}
SC (cm)	24.1±0.66^{bc}	27.5±0.51^{a}	25.8±1.55^{ab}	25.6±0.53^{b}	21.5±1.90^{c}

^{a,b,c,d} Means with different superscript across rams of different breeds are significantly different (p<0.05), NR = Not Recorded, BW = Body Weight, BL = Body Length, HG = Heart Girth, HW = Height at Withers, SW = Shoulder Width, RH = Rump Height, RW = Rump Width, HL = Head Length, HDW = Head Width, HNL = Horn Length, NL = Neck Length, EL = Ear Length, EW = Ear Width, TL = Tail Length, TC = Tail Circumference, CBC = Cannon Bone Circumference, CBL = Cannon Bone Length, SC = Scrotal Circumference

Table 4: Morphological traits of ewes across different sheep breeds

Trait	Damara	Dorper	Karakul	Meat-master	Tswana
BW (kg)	51.7±1.72^{b}	59.0±1.12^{a}	52.4±1.02^{b}	57.5±1.15^{a}	39.2±1.98^{c}
BL (cm)	68.1±0.88^{c}	75.6±0.57^{a}	72.0±0.52^{b}	71.8±0.59^{b}	56.5±1.01^{d}
HG (cm)	83.6±1.11^{b}	87.3±0.72^{a}	88.6±0.66^{a}	87.4±0.75^{a}	74.9±1.28^{c}
HW (cm)	71.5±0.65^{a}	64.2±0.42^{d}	66.4±0.39^{c}	69.8±0.44^{b}	63.0±0.75^{d}
SW (cm)	21.7±0.51^{c}	25.0±0.33^{a}	25.7±0.30^{a}	23.6±0.34^{b}	17.3±0.59^{d}
RH (cm)	73.1±0.59^{a}	63.3±0.38^{d}	65.7±0.35^{c}	70.1±0.39^{b}	62.0±0.68^{d}
RW (cm)	18.6±0.36^{c}	24.0±0.23^{a}	23.1±0.21^{b}	22.7±0.24^{b}	17.0±0.41^{d}
HL (cm)	19.5±0.34^{a}	18.8±0.22^{ab}	18.2±0.20^{b}	19.2±0.23^{a}	16.2±0.40^{c}
HDW (cm)	10.5±0.18^{d}	11.3±0.11^{c}	12.1±0.11^{a}	11.7±0.12^{b}	8.7±0.21^{e}
HNL (cm)	7.9±1.79	NR	11.0±6.93	NR	NR
NL (cm)	28.3±0.84^{a}	28.5±0.54^{a}	27.7±0.50^{ab}	26.3±0.56^{b}	19.6±0.97^{c}
EL (cm)	13.3±0.24^{a}	12.4±0.15^{b}	13.3±0.14^{a}	12.7±0.16^{b}	11.5±0.27^{c}
EW (cm)	6.6±0.10^{b}	6.3±0.07^{c}	7.6±0.06^{a}	6.9±0.07^{b}	6.0±0.12^{d}
TL (cm)	51.0±1.13^{a}	NR	NR	40.3±0.76^{b}	28.0±7.48^{b}
TC (cm)	17.0±0.62^{a}	NR	NR	12.9±0.41^{b}	12.5±4.10^{b}
CBC (cm)	6.7±0.15^{c}	7.9±0.10^{a}	7.4±0.09^{b}	7.7±0.10^{a}	6.7±0.18^{c}
CBL (cm)	15.1±0.27^{a}	13.3±0.17^{c}	14.0±0.16^{b}	15.1±0.18^{a}	11.0±0.31^{d}

^{a,b,c,d,e} Means with different superscript across ewes of different breeds are significantly different (p<0.05), NR = Not Recorded, BW = Body Weight, BL = Body Length, HG = Heart Girth, HW = Height at Withers, SW = Shoulder Width, RH = Rump Height, RW = Rump Width, HL = Head Length, HDW = Head Width, HNL = Horn Length, NL = Neck Length, EL = Ear Length, EW = Ear Width, TL = Tail Length, TC = Tail Circumference, CBC = Cannon Bone Circumference, CBL= Cannon Bone Length

Table 5: Morphological traits of castrates across different breeds

Trait	Damara	Dorper	Karakul	Meat-master	Tswana
BW (kg)	80.5±8.06^{a}	58.9±2.85^{b}	51.3±6.58^{bc}	71.0±4.31^{a}	40.8±3.44^{c}
BL (cm)	73.0±4.11^{ab}	74.4±1.45^{b}	70.3±3.36^{b}	80.3±2.20^{a}	55.5±1.75^{c}
HG (cm)	102.5±5.22^{a}	88.1±1.84^{b}	82.3±4.26b^{c}	93.4±2.79^{a}	75.9±2.22^{c}
HW (cm)	79.5±3.07^{a}	66.6±1.08^{b}	69.3±2.50^{b}	75.0±1.64^{a}	64.3±1.31^{b}
SW (cm)	24.5±2.41^{a}	27.0±0.85^{a}	25.0±1.96^{a}	28.1±1.29^{a}	18.8±1.03^{b}

RH (cm)	81.5±2.76[a]	65.3±0.98[cd]	69.0±2.25[bc]	73.6±1.48[b]	63.5±1.18[d]
RW (cm)	23.5±1.67[a]	24.1±0.59[a]	21.7±1.36[a]	24.9±0.89[a]	17.2±0.71[b]
HL (cm)	20.0±1.61[a]	19.2±0.57[a]	19.0±1.32[a]	20.6±0.86[a]	15.9±0.69[b]
HDW (cm)	12.5±0.86[ab]	11.7±0.30[b]	11.3±0.70[b]	12.9±0.46[a]	8.6±0.37[c]
HNL (cm)	12.3±6.93	NR	14.8±6.93	NR	NR
NL (cm)	24.0±3.94[ab]	28.1±1.39[a]	28.0±3.22[a]	31.6±2.11[a]	19.1±1.68[b]
EL (cm)	13.5±1.11	11.9±0.39	13.7±0.91	13.1±0.59	11.7±0.47
EW (cm)	6.8±0.48[ab]	6.3±0.17[b]	6.3±0.39[b]	7.0±0.26[a]	6.0±0.20[b]
TL (cm)	56.0±5.29[a]	NR	NR	43.4±2.83[b]	19.0±7.48[c]
TC (cm)	26.9±2.90[a]	NR	NR	20.0±1.55[b]	31.5±4.10[a]
CBC (cm)	8.5±0.73[ab]	8.2±0.26[a]	6.7±0.59[c]	8.4±0.39[a]	7.2±0.31[bc]
CBL (cm)	17.5±1.25[a]	13.6±0.44[b]	13.3±1.02[bc]	16.6±0.67[a]	11.6±0.53[c]

[a,b,c,d] Means with different superscript across castrates of different breeds are significantly different ($P<0.05$), NR=Not Recorded, BW=Body weight, BL=Body length, HG=Heart girth, HW=Height at withers, SW=Shoulder width, RH=Rump height, RW=Rump width, HL=Head length, HDW=Head width, HNL=Horn length, NL=Neck length, EL=Ear length, EW=Ear width, TL=Tail length, TC=Tail circumference, CBC=Cannon bone circumference, CBL=Cannon bone length.

Discussion

The results indicate distinct morphological differences between the different sheep breeds under study in Botswana. The discrepancies in the coat color pattern of Tswana sheep reported in the current study from those reported by Bolowe *et al*. (2021) might be attributed to differences in the management and production systems of Tswana sheep between the two studies. Tswana sheep in the study by Bolowe *et al*. (2021) were extensively kept in communal areas and thus had greater chances of random mating with a greater pool of males with different color coats and patterns. In the current study, the Tswana sheep used was a conservation flock that had been kept as an enclosed small population for thirty (30) years and might have been exposed to inbreeding and thus reduced variation at the coat color locus. The findings of the current study are, however, consistent with Bolowe *et al*. (2021), who also reported a higher percentage of Tswana sheep with predominantly white coat color. The white coat color could be an adaptive trait as it absorbs less radiation, thereby allowing Tswana sheep to survive the extremely hot environmental conditions of the country. The predominantly black color of the Karakul agrees with Hailemariam *et al*. (2018), who also found that sheep in the Gamogofa zone of Ethiopia were predominantly black. The black coat color helps sheep absorb enough solar radiation to maintain homeostasis. The Karakul sheep in the current study were kept in Kgalagadi district, which is the coldest part of Botswana, and the black coat color is thus an adaptive strategy against extreme cold weather. The observed brown coat color of Damara and Meat-master sheep is also an adaptive mechanism that helps the sheep to camouflage with the red sandy soil landscape, thereby eluding prey. However, differing from the current results, Becker and Fourie (2021) reported red and white coat color as the dominant color in Meat-master sheep of South Africa. The tail morphology and ear orientation of Damara and Meat-master sheep reported in the current study are in line with Abera *et al*. (2014), who reported long fat tails with straight tips for indigenous sheep in the Selale area of Ethiopia. The spiral horn shape of the Damara is consistent with Almeida (2011), who reported that spiral horns were common in Damara sheep irrespective of sex.

The significant influence of sex on body weight and most linear body measurements reported in the current study was found also by Mohammed *et al*. (2018) in Dorper and local sheep of Ethiopia. This indicates sexual dimorphism in body weight and morphometric traits of sheep, which usually favors males over females (Nsoso *et al*., 2004; Michael *et al*., 2016; Mohammed *et al*., 2018; Bolowe *et al*., 2021). The generally higher body weight and morphometric traits of Dorper, Karakul, and Meat-master rams over their female counterparts are in line with Selala and Tyasi (2022) and Musavi *et al*. (2022). The Dorper and Karakul rams in the current study were heavier as compared to those reported by Fourie *et al*. (2002) and Musavi *et al*. (2022) in the South African Dorper and Northern Afghanistan Karakul rams, respectively. This indicates the influence of environment and possibly artificial selection on the morphometric diversity of animal genetic resources. The similarities in body weight and most linear body measurements of Tswana sheep in this study, which is an indication of a lack of sexual dimorphism, are in line with those of Abera *et al*. (2014) and Michael *et al*. (2016), who found no significant differences between rams and ewes in body weight and most linear body measurements in Indigenous sheep breeds of Ethiopia. Furthermore, the Tswana sheep population used in this study was from a closed conservation flock where interbreeding was limited whilst inbreeding is inevitably high, resulting in a homogenous population with reduced variation between sexes of the breed. Generally, the variation in morphometric traits between rams and ewes may be attributed to the differences in the function of the endocrine system between these sexes, where testosterone in rams is believed to enhance muscle development while estrogen in ewes limits growth (Baneh and Hafezian, 2009).

DOI: 10.3844/ajavsp.2025.53.63

The variation in morphometric traits between rams of different breeds is consistent with Agbaye *et al*. (2021), who found a similar trend in Balami, Ouda, Yankasa, and West African Dwarf rams in Nigeria. However, the superiority in body weight in Meat-master and Karakul rams over indigenous Tswana and Damara was attributed to the fact that the Dorper and Meat-master are composite exotic breeds that have been artificially selected for mutton production; as such, they tend to gain more muscle compared to their indigenous counterparts. The similarities between Damara and Tswana sheep could be aligned to the fact that Damara and Tswana breeds do not gain much muscle, and they are naturally smaller in size compared to their exotic counterparts. This is deemed a survival trait as smaller animals generally require less feed (Becker and Fourie, 2021) and can better escape predators than heavier meat breeds. A similar trend where Indigenous breeds recorded lower values in body weight and most morphometric traits than composite and exotic counterparts was observed by Mavule (2012), Mohammed *et al*. (2018), and Bolowe *et al*. (2021). The heavier body weight of Meat-masters over Dorper, Damara, and Tswana rams is in accord with Becker and Fourie (2021), who found a higher body weight (73.8 kg) in Meat-master rams. This could be because Meat-master is a composite breed bred out of the Dorper and the Damara; therefore, it benefits from heterosis and performs better than the average of both its parents (Becker and Fourie, 2021). The significantly lower ($p<0.05$) cannon bone circumference of the Damara and Tswana rams over other breeds reported in the current study could be an adaptive feature that allows these indigenous breeds to walk long distances in search of pasture and to be able to flee from predators. Becker and Fourie (2021) reported that the Meat-master sheep acquired adaptive traits from its parent breed, Damara, which might have contributed to the Meat-master having similar cannon bone circumference with Damara and Tswana even though it is a meat animal. The significantly higher ($p<0.05$) cannon bone circumference of Dorper and Karakul rams over other breeds may be attributed to the fact that a strong, thick cannon bone is needed to support the heavy body weight of the Dorper and Karakul rams. Higher cannon bone circumference is one of the characteristics of a good meat animal (Cloete *et al*., 2000). The largest scrotal circumference of Dorper rams in this study is indicative of the breed's good reproductive ability, surpassing its counterparts under study. Cloete *et al*. (2000) reported that Dorper rams reach sexual maturity early, which might have contributed to them having significantly higher scrotal values as compared to other breeds. Large scrotal circumference is a favorable trait when selecting breeding rams as it has a positive correlation with sperm production (Van Wyk, 2010) and further has a desirable negative correlation with age at puberty of the progeny. The scrotal circumference of Dorper rams in the current study was, however, lower than that reported by Fourie *et al*. (2002) (32.55 cm) for Dorper rams of South Africa. The scrotal circumference of Dorper rams in this study is like that reported by Michael *et al*. (2016) (27.5 cm) for East Gojam indigenous sheep types of Ethiopia.

In ewes, the observed variations in body weight and most linear body measurements across the different breeds are consistent with Mohammed *et al*. (2018), who reported significant differences in body weight and most linear body measurements between pure-bred Dorper, Dorper crosses and indigenous Ethiopian sheep. Dorper ewes in this study were heavier (59.0 kg) than those reported by Mohammed *et al*. (2018) (32.41 kg) for Dorper ewes in Ethiopia. The differences might be due to alternative levels of evolutionary forces such as mutations and selection, which make animals evolve even in morphological features to better survive and reproduce in each environment. The Tswana and Karakul ewes in this study were much heavier than those reported by Bolowe *et al*. (2021) and Musavi *et al*. (2022) in Botswana and North Afghanistan, respectively. The differences in body weight might be attributed to the differences in the management of the animals under study. Those in the current study were kept under semi-intensive management systems where there is constant supplementation, whereas those in the study by Bolowe *et al*. (2021) were raised in communal areas where there is high competition for feed and supplementation is limited. Contrary to the current findings, Hailemariam *et al*. (2018) reported a body weight of 24.0 kg for mature Indigenous ewes, which indicates that Indigenous sheep breeds in this study are much heavier than those found in the Gamogofa zone of Ethiopia. All the breeds in this study were lighter than the Ouled-Djellal breed of Algeria (Harkat *et al*., 2017). The significantly higher values for most linear body measurements (HW, RH, HDW, HL, EL, NL, TL, TC, and CBL) of Damara ewes over their exotic counterparts are adaptive traits of the indigenous breed. Von Wielligh (2001) reported that the Damara diet may constitute about 60% of browsing materials during feed scarcity, hence the need for long necks to reach higher tree leaves. Longer cannon bone length and thin cannon bone circumference help the indigenous breeds to run away from predators and enable them to walk long distances in search of pasture and water. Furthermore, the higher values for tail morphology in the indigenous breeds (Damara and Tswana) are also a survival trait in that the fat tails serve as a fat reserve, which is mobilized during periods of feed scarcity. Almeida (2011) reported that the fat tail found in indigenous breeds is essential for animals to better tolerate seasonal weight losses and extreme temperatures that are experienced in their locations.

In castrates, the significantly higher body weight and linear body measurements of Damara and Meat-master might be because Damara castrates used in the study were much older (2 years and above) compared to other breeds which had all age categories of mature sheep (1 year and above) represented. Several authors (Gebre, 2007; Hailu *et al*., 2020; Bolowe *et al*., 2021) reported that body weight and most morphological traits increase with age, which might explain significantly higher values in Damara castrates than their exotic counterparts. Meat-master castrates in the current study were heavier than their age-matched Dorper counterparts, indicating their capability to produce more meat than the Dorper. Becker and Fourie (2021) highlighted that the Meat-master, as a composite breed bred from Damara and Dorper, has inherited the ability to produce heavier carcasses from one of its parent breeds, the Dorper, and thus benefits from hybrid vigor to outperform the Dorper.

Conclusion

Tswana sheep are distinguished by patchy coat color patterns, with white being the dominant coat color and absence of horns in both sexes. Damara, Dorper, Karakul, and Meat-master have plain coat color patterns with brown, black head, and white body, black and brown being the predominant coat colors, respectively. Breed and sex had a significant influence on body weight and linear body measurements across all five sheep breeds. Tswana sheep had the lowest values for body weight and most morphometric traits in all the sexes compared to other sheep breeds. Meat-master, Dorper, and Karakul sheep breeds had higher body weights and more linear body measurements for both intact rams and ewes than indigenous sheep breeds (Tswana and Damara). Generally, there was sexual dimorphism for body weight, and most morphometric traits favored males over females. This information is key and a prerequisite that informs and guides policymakers on the development of policies and strategies that are intended for the conservation, management, improvement, and, most importantly, sustainable future utilization of these vital animal genetic resources.

Acknowledgment

The authors are grateful to the Ministry of Agriculture for allowing us to use the Lobu field station to collect data. We sincerely thank Botswana University of Agriculture and Natural Resources (BUAN) for financing the study and supplying the necessary data collection tools. Additionally, Lindile Chiwaya, BUAN coworkers, and Lobu employees are acknowledged for their crucial support throughout the data collection procedure.

Funding Information

The authors would like to acknowledge Botswana University of Agriculture and Natural Resources (BUAN) for funding the research project.

Author’s Contributions

Kaelo Pelotshweu: Conceptualization, methodology, software, investigation, data curation, writing-original draft preparation, visualization.

Monosi Andries Bolowe: Conceptualization, methodology, software, writing-review and editing, supervision.

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Ketshephaone Thutwa: Validation, formal analysis, writing review and editing, supervision.

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Ethics

This study was performed strictly following protocols and guideline procedures approved by the Research Technology Development and Transfer Committee of Botswana University of Agriculture and Natural Resources. The approval number is BUAN-ACUC-2024-07.

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