PHENOTYPIC CHARACTERIZATION, CORRELATIONS BETWEEN BODY WEIGHT AND LINEAR BODY MEASUREMENTS AND REGRESSION EQUATIONS FOR PREDICTION OF LIVE WEIGHT IN DIFFERENT SHEEP BREEDS OF BOTSWANA

MASTER OF SCIENCE IN ANIMAL SCIENCE

(ANIMAL BREEDING AND REPRODUCTION)

KAELO PELOTSHWEU

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A dissertation submitted to the Department of Animal Sciences in partial fulfilment of the requirements for the degree of Master of Science (MSc) in Animal Science (Animal Breeding and Reproduction)

KAELO PELOTSHWEU

Faculty of Animal and Veterinary Sciences
Department of Animal Sciences
Botswana University of Agriculture and Natural Resources

Main supervisor: **Prof. P.M. Kgwatalala**

Co-supervisor: **Dr. K. Thutwa**

August 2024

DECLARATION

I, Kaelo Pelotshweu hereby declare that this dissertation submitted by me to Botswana University of Agriculture and Natural Resources for the degree of Master of Science in Animal science (Animal Breeding and Reproduction) is my own independent work and has not been previously submitted by me at another University to obtain any qualification. All references and assistance rendered during the production of this work have been duly acknowledged.

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Kaelo Pelotshweu

APPROVAL

Main supervisor's name   Date
Signature

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Co-supervisor's name   Date
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Head of Department's name   Date
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GENERAL ABSTRACT

The study was conducted to phenotypically characterize and establish relationships between body weight and linear body measurements, and to develop prediction equations for body weight using linear body measurements for Tswana, Dorper, Damara, Meat-master, and Karakul sheep breeds kept under the ranch management system of Botswana. Qualitative and quantitative data were collected from a total of five hundred and ninety-five (595) adult sheep comprising of the Damara (44 females and 35 males), Dorper (105 females and 72 males), Karakul (126 females and 9 males), Meat-master (98 females and 58 males) and Tswana (33 females and 15 males) sheep breeds. The sheep populations at the study site determined the sampling size since almost all adult animals participated in the study. The dentition procedure was used to determine the age of the animals and only those with one pair of permanent incisors (1PPI) and above participated in the study. A total of ninety four animals (Damara: 20, Dorper: 30, Karakul: 16, and Meat-master: 28) were randomly sampled for the development of prediction equations fo live weight using linear body measurements in the four sheep breeds.

Damara and Meat-master were characterized by brown coat color and straight long fat and moderate tails, respectively. Dorper and Karakul breeds have plain coat color pattern with Dorper having black head and white body while Karakul have black coat color. A patchy coat color pattern with predominantly white color characterized Tswana sheep. Breed and sex significantly influenced body weight and most linear body measurements, with males being heavier across all the breeds than females. Meat-master rams were the heaviest (73.8±1.60 kg), followed by Karakul (70.2±4.65 kg), Dorper (68.9±1.52 kg), Damara (55.5±1.98 kg), and lastly, Tswana (49.3±5.70 kg), while Dorper ewes were the heaviest (59.0±1.12 kg), followed by Meat-master (57.5±1.15 kg), Karakul (52.4±1.02 kg), Damara (51.7±1.72 kg) and lastly, Tswana (39.2±1.98 kg). 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. There was sexual dimorphism, with body weight and most linear body measurements favoring males (rams and castrates) as compared to females in almost all the breeds.

There were strong, positive correlation coefficients between body weight and heart girth in Tswana, Dorper, Damara, Meat-master, and Karakul sheep breeds, irrespective of sex with males having higher correlation coefficients than females. Body length in males across the breeds had a much higher correlation coefficient with body weight compared to height at withers. Linear body measurements like heart girth, body length, height at withers, neck length, cannon bone length, cannon bone circumference and scrotal circumference in males were used to estimate the body weight of Dorper, Damara, Meat-master and Karakul sheep breeds. The following equations were therefore found fit to accurately estimate body weight of Dorper females $y = -102.29+0.26HG - 0.77HW+0.34BL+4.71NL+3.61CBL$ and males $y = -20.13+0.71HG+1.09HW - 2.05NL$, Karakul females $y = -107.08+0.58HG+0.69HW+5.58CBL$ and males $y = -137.20+1.60HG+0.41BL+0.61SC$, Meat-master females $y = -102.11+1.02HG+1.00BL - 1.71CBL+0.75NL$ and males $y = 16.45+0.42HG+0.79HW+0.34SC - 2.05NL$, and Damara females $y = 77.80 - 0.48HG - 3.12HW - 8.38BL - 6.06NL+25.44CBL+66.26CBC$ and males $y = -1063.34+8.02HG+0.86HW+4.64BL$, where y is the body weight and HG, HW, BL, NL, CBL, CBC, SC are heart girth, height at withers, body length, neck length, cannon bone length, cannon bone circumference and scrotal circumference, respectively. Heart girth accounted for more variability in the prediction model for all the breeds, both males and females, except for Damara males. Heart girth and body length explained more variability in the model used to predict the body weight of Damara males, which means these traits can be used as selection criteria for body weight. The addition of more independent variables increases the accuracy of the prediction equation.

Keywords: Characterization, sheep, correlation, regression, body weight

DEDICATION

This work is dedicated to my mother, Mrs Keletso Modise, for raising me with love and patience through life difficulties and investing in my academic journey and success. To my grandmother Mrs Kebolebale Pelotshweu, thank you for introducing me to the world of Agriculture.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
GENERAL INTRODUCTION

1.1 Background

One of the most crucial steps in the history of humans was the domestication of livestock, as it resulted in the start of agricultural activities. According to Chessa *et al.* (2009), animals from the subfamily Caprinae, being the sheep and goat are regarded as the first livestock animals to be domesticated. Domestic sheep is believed to have descended from Asiatic Mouflon about 11 000 years ago. As indicated by archaeological and genetic findings, domestication of sheep began at low management levels of the wild mouflon, followed by increased management until a point of full domestication (Zeder, 2011).

Today indigenous sheep in Africa have been broadly divided into two groups according to tail morphology, which are fat-tailed and thin-tailed sheep. According to Muigai & Hanotte (2013), these sheep occupy different parts of Africa with fat-tailed sheep dominating most parts of Africa (North, Eastern and Southern Africa) and thin-tailed sheep being found in a few areas of Africa (Morocco, Sudan, and West Africa). The sheep are classified as indigenous because of their ability to thrive under traditional management systems with limited resources. Since their introduction into Africa, sheep have played an important role in improving the livelihoods of people in developing countries especially those in rural areas. In Botswana, small stock production has been overpowered by cattle production over the years, due to the dependence of the country on beef export. This has led to most of the small stock production being practiced under the traditional systems (extensive, subsistence) and the focus of the commercial system being cattle production (Burgess, 2006). Small stock (sheep and goat) has always been kept by Botswana farmers for subsistence purposes, whereby the animals provide milk and meat for family nutrition, hides, manure and payment of dowry in social activities (Aganga & Aganga, 2015). The animals are only sold when there is a need for emergency cash for the families like sending children to school.

Research has shown that there has been little interest in sheep production as compared to cattle and goat production, which has resulted in the sheep population being much lower compared to other ruminant animals. According to Statistics Botswana (2016), the sheep population was about 227 247, which is way lower when compared to that of goats being 1 605 642. The majority of farmers in Botswana keep the indigenous Tswana sheep as it has proved to be more adapted to the harsh climatic conditions of Botswana with the ability to utilize limited feed resources and being disease and parasite-tolerant (Nsoso *et al.*, 2004). Other indigenous sheep like Zulu and Pedi from South Africa have been reported by Ngcobo *et al.* (2022) to withstand drought, with good tolerance to endoparasites in their local areas. There are various sheep breeds found in Botswana including Tswana, Dorper, Karakul, Meat-master and Damara, but the most utilized sheep breed after the indigenous Tswana breed is Dorper sheep (Masilo & Madibela, 2003). Damara sheep is characterized by long horns, fat tail and just like Tswana sheep is well adapted to seasonal changes in forage availability and parasites. According to Ngcobo *et al.* (2022), the large body frame of the Damara sheep has made it indispensable in the development of composite breeds like Meat-master. One of the composite breeds developed in South Africa is the Dorper sheep which was developed from Dorset Horn and Blackhead Persian and is known for its high fertility and high growth rate (Qiao *et al.*, 2022). This makes the Dorper sheep ideal for crossbreeding in most locations throughout the world.

The sheep genetic resource diversity makes it possible to implement different animal improvement strategies (Hailu & Getu, 2015). According to Asamoah-Boaheng & Sam (2016), characterizing animal genetic resource (AnGR) includes specifying the qualitative and quantitative traits of a particular breed population. Characterizing animals in their native environment makes it easier to identify traits specific to a particular breed that enable it to be better adapted and survive in a particular area. This will make it easy to select the appropriate breeding programs that will maximize production with little threat to the genetic resources of the breeds (FAO, 2012). According to Hailu *et al.* (2020), since phenotypic characterization is a pre-requisite for breed conservation and sustainable utilization, it will result in sustainable food security being maximized with minimal pressure on the environment.

Phenotypic characterization of Tswana sheep in all districts of Botswana was done about two decades ago by Nsoso *et al.* (2004). Other studies like that of Bolowe *et al.* (2021) focused on extensively managed farms in the Southern districts of Botswana. Even though research has indicated that Dorper sheep has been characterized in areas like Ethiopia (Mohammed *et al.*, 2018), limited information exists on the phenotypic characterization of Dorper sheep in Southern African countries. The most recent research in South Africa by Selala & Tyasi (2022), focused on Dorper lambs which may not reflect linear body measurements of mature Dorper sheep. Literature indicates that Karakul sheep have only been phenotypically characterized outside Southern Africa. The latest study on morphological characterization of Karakul sheep was done by Musavi *et al.* (2022) in North Afghanistan. Karakul sheep found in Southern African environments may be different from those found in North Afghanistan due to different climatic conditions and selection practices. Literature on the phenotypic characterization of the Meat-master breed is very scarce even though the breed was developed in South Africa, with most studies focusing on the production performance of the breed and its carcass quality (Becker, 2021). Literature also focused on the performance of the Damara sheep breed and not on its morphological characterization (Almeida, 2011; Kandiwa *et al.*, 2019; Ngcobo *et al.*, 2022).

Phenotypic characterization is also a pre-requisite to the design of effective improvement programs as the phenotypic data can aid in the selection of breeding stock. Selection is usually based on traits of economic importance, and as such phenotypic correlations between traits can be used to predict the outcomes of selection (Manyeula *et al.*, 2020). High correlation coefficients between body weight and linear body measurements make it easy to develop regression prediction equations that can be used to estimate the body weight of sheep in the absence of the weighing scales (Castillo *et al.*, 2023). Interrelationships between body weight and other morphometric traits have been done in Botswana on indigenous Tswana sheep and goats (Sebolai *et al.*, 2012; Temoso *et al.*, 2017; Bolowe *et al.*, 2021). Few studies have also been done on phenotypic correlations between body weight and linear body measurements in other sheep breeds like Dorper and Meat-master in South Africa (Becker, 2021; Selala &Tyasi, 2022) and Dorper in Ethiopia (Mohammed *et al.*, 2018). There is no literature on phenotypic correlations between body weight and linear body measurements in the Karakul and Damara sheep breeds.

1.2 Problem Statement

From the review of the literature, very little research has been done on the phenotypic characterization of different sheep breeds found in Botswana like the Tswana, Dorper, Karakul, Meat-master, and Damara. Phenotypic characterization data serve as a baseline for future monitoring of trends and evaluation of the effectiveness of selection programs. Phenotypic characterization data is also used for the estimation of genetic parameters and prediction purposes (correlated responses and development of regression equations) in genetic improvement programs. Phenotypic characterization should also not be a once-off exercise as it also serves the inventory and monitoring of animal genetic resources. Phenotypic characterization of animal genetic resources should also be location-specific as data obtained in one country does not necessarily apply in another country as animal genetic resources are shaped by the environment and different evolutionary forces that are location-specific. Gaps exist in the phenotypic characterization of the sheep genetic resources of Botswana and breeds like the Dorper, Damara, Meat-master and Karakul have never been phenotypically characterized in terms of body weight and linear body measurements in Botswana. The lack of phenotypic characterization data also implies that phenotypic correlations between body weight and other linear body measurements and regression equations for the estimation of body weight in the different sheep breeds have never been evaluated.

1.3 Justification

Phenotypic characterization (Body weight and Linear body measurements) of the Tswana, Dorper, Karakul, Meat-master and Damara sheep genetic resources of Botswana will provide baseline data for future monitoring of trends and inform genetic improvement programs on responses to selection. The baseline data can also be used to inform appropriate conservation and breed improvement programs and strategies.

1.4 Aim and Objectives

The aim of the study was to phenotypically characterize, estimate phenotypic correlations between body weight and linear body measurements and develop prediction equations for live weight using linear body measurementsi for Tswana, Dorper, Karakul, Meat-master and Damara sheep breeds of Botswana.

1.4.1 Specific objectives

The specific objectives of the study were;

1) To compare body weights and linear body measurements of Tswana, Dorper, Karakul, Meat-master and Damara sheep breeds of Botswana.
2) To estimate correlation coefficients between body weight and linear body measurements in Tswana, Dorper, Karakul, Meat-master and Damara sheep breeds of Botswana.
3) To develop prediction equations for live weight using linear body measurements for the Dorper, Karakul, Meat-master and Damara sheep breeds of Botswana.

1.5 Hypotheses

The following hypotheses are linked to the objectives above:

1) There are no significant differences in body weight and linear body measurements of Tswana, Dorper, Karakul, Meat-master and Damara sheep breeds of Botswana.
2) There are no significant differences in correlation coefficients between body weight and linear body measurements in Tswana, Dorper, Karakul, Meat-master and Damara sheep breeds of Botswana.
3) Prediction equations for body weight using linear body measurements are similar for Tswana, Dorper, Karakul, Meat-master and Damara sheep breeds of Botswana.

1.6 References

Aganga, A.O. and A.A. Aganga (2015) Quality assurance in goat meat production for food safety in Botswana. *Asian Journal of Biological Sciences, 8* (2), 51-56.

Almeida, A.M. (2011). The Damara in the context of Southern Africa fat-tailed sheep breeds. *Tropical Animal Health Production,* 43, 1427-1441.

Asamoah-Boaheng, M., & Sam, E.K. (2016). Morphological characterization of breeds of sheep: a discriminant analysis approach. *SpringerPlus,* 5, 69.

Becker, S.J. (2021). Phenotypic characterisation of Meatmaster sheep using quantitative and qualitative trait analysis. *Masters thesis.* Central University of Technology. Free State, South Africa.

Bolowe, M.A., Thutwa, K., Kgwatalala, P.M., Monau, P.I., & Malejane, C. (2021). Phenotypic characterization of indigenous Tswana sheep population in selected Districts of Southern Botswana. *African Journal of Agricultural Research, 17* (10), 1268-1280.

Burgess, J. (2006). Country Pasture/Forage Resource Profiles: Botswana. Food and Agriculture Organization of the United Nations. Retrieved July 3, 2022, from http://www.fao.org/ag/agp/agpc/doc/counprof/ PDF%20files/Botswana.pdf.

Castillo, P.E., Macedo, R.J., Arredondo, V., Zepeda, J.L., Valencia-Posadas, M., & Haubi, C.U. (2023). Morphological Description and Live Weight Prediction from Body Measurements of Socorro Island Merino Lambs. *Animals,* 13, 1-11.

Chessa, B., Pereira, F., Arnaud, F., Amorim, A., Goyache, F., Mainland, I., Kao, R.R., Pemberton, J.M., Beraldi, D., Stear, M., Alberti, A., Pittau, M., Iannuzzi, L., Banabazi, M.H., Kazwala, R., Zhang, Y.P., Arranz, J.J., Ali, B.A., Wang, Z., Uzun, M., Dione, M., Olsaker, I., Holm, L.E., Saarma, U., Ahmad, S., Marzanov, N., Eythorsdottir, E., Holland, M.J., Ajmone-Marsan, P., Bruford, M.W., Kantanen, J., Spencer, T.E., & Palmarini, M. (2009). Revealing the history of sheep domestication using retrovirus integrations. *Science,* 324, 532-536.

FAO. (2012). Phenotypic characterization of Animal Genetic Resources. url: www.fao.org/docrep/015/ i2686e/i2686e00.pdf.

Hailu, A., & Getu, A. (2015). Breed Characterization: Tools and Their Applications. *Open Access Library Journal,* 2: e1438.

Hailu, A., Mustefa, A., Aseged, T., Assefa, A., Sinkie, S., & Tsewene, S. (2020). Phenotypic characterization of sheep population in Tahtay Maichew district, Northern Ethiopia. *Genetic Resources, 1* (2), 12-20.doi:10.46265/genresj.SHBD3744.

Kandiwa, E., Mushonga, B., Madzingira, O., Samkange, A., Bishi, A., & Tuaandi, D. (2019). Characterizaion of Oestrus Cycles in Namibian Swakara and Damara Sheep through Determination of Circannual Plasma Progesterone Levels. *Journal of Veterinary Medicine,* 18, 1-6.

Manyeula, F., Tumagole, O., & Kgwatalala, P. (2020). Phenotypic Correlations among Various Egg Quality Traits in Pearl Grey, Lavender, Royal Purple, and White Varieties of Helmeted Guinea Fowl. *Journal of World Poultry Research, 10* (4), 580-586.

Masilo, B.S., & Madibela, O.R. (2003). *Report on the State of the World Animal Genetic resources (AnGR): Botswana Country Report*. Gaborone, Botswana: Agricultural Research.

Mohammed, J., Abegaz, S., Lakew, M., & Tarekegn, G.M. (2018). Phenotypic Characterization of Dorper, Local Sheep and Their Crossbred Sheep Population in North Eastern Amhara, Ethiopia. *Journal of Biology, Agriculture and Healthcare, 8* (1), 15-25.

Muigai, A.W.T., & Hanotte, O. (2013). The Origin of African Sheep: Archaeological and Genetic Perspectives. *Afr Archaeol Rev,* 30, 39-50.

Musavi, S. A. A., Khadimiyan, A. M., & Azimi, A. M. (2022). Morphological Characterization of Karakul Sheep in North Part of Afghanistan. *Voice of the Publisher,* 8, 16-25.

Ngcobo, J.N., Nedambale, T.L., Nephawe, K.A., Mpofu, T.J., Chokoe, T.C., Ramukhithi, F.V. (2022). An Update on South African Indigenous Sheep Breeds' Extinction Status and Difficulties during Conservation Attempts: A Review. *Diversity,* 14, 516.

Nsoso, S.J., Podisi, B., Otsogile, E., Mokhutshwane, B.S., & Ahmadu, B. (2004). Phenotypic Characterization of Indigenous Tswana Goat and Sheep Breeds in Botswana: Continuous Traits. *Tropical Animal Health and Production,* 36, 789-800.

Qiao, G., Xu, P., Guo, T., Wu, Y., Lu, X., Zhang, Q., He, X., Zhu, S., Zhao, H., Lei, Z., Sun, W., Yang, B., & Yue, Y. (2022). Genetic Basis of Dorper Sheep (*Ovis aries*) Revealed by Long-Read De Novo Genome Assembly. *Front. Genet.* 13, 846449.

Sebolai, B., Nsoso, S. J., Podisi, B., & Mokhutshwane, B. S. (2012). The estimation of live weight based on linear traits in indigenous Tswana goats at various ages in Botswana. *Tropical Animal Health Production, 44* (4), 899-904.

Selala, L.J., & Tyasi, T.L. (2022). Using Morphological Traits to Predict Body Weight of Dorper Sheep Lambs. *World Veterinary Journal, 12* (1), 66-73.

Statistics Botswana. (2016). *Agricultural census brief report of 2016-2022*. Retrieved from https://www.statsbots.org.bw/agriculture.

Temoso, O., Coleman, M., Baker, D., Morley, P., Baleseng, L., Makgekgenene, A., & Bahta, S. (2017). Using path analysis to predict body weight from body measurements of goats and sheep of communal rangelands in Botswana. *South African Journal of Animal Science, 47* (6), 854-863.

Zeder, M. A. (2011). The origins of agriculture in the Near East. *Current Anthropology,* 52 (4), S221–S235.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of sheep into Africa

After domestication, the first domestic sheep from Mesopotamia entered the African continent through two distinct entry points, the horn of Africa and the northeastern part of Africa (Hanotte *et al.*, 2002). It is believed that the first domestic sheep to enter Africa were thin-tailed, but currently, the northern part of Africa is dominated by fat-tailed sheep. This may indicate that another migration of sheep into Africa might have occurred, which resulted in fat-tailed sheep replacing thin-tailed sheep in northern Africa (Muigai & Hanotte, 2013). The predominance of fat fat-tailed sheep population may also indicate that evolutionary forces like selection (natural and artificial), mutation, migration and random genetic drift may have occurred resulting in the total replacement of thin-tailed sheep by fat-tailed sheep. According to Moradi *et al.* (2012), there is a likelihood that fat-tailed sheep may have been selected from thin-tailed sheep to enhance adaptation and survival in various climatic conditions of Africa. The path followed by sheep to reach Southern Africa is still unknown, but evidence suggests that there was sheep production in Blombos Southern Cape Coast around 1987 years ago (Henshilwood, 1996).

2.2 Importance of variation in sheep

Since the events of domestication, sheep populations have occupied different parts of the world with different climatic conditions, natural ecosystems and cultures which enabled them to evolve in a way that best suited their location. This has resulted in various sheep breeds being developed worldwide and increasing the diversity of the sheep's genetic resources. According to Hailu & Getu (2015), evolutionary forces like selection, migration, random genetic drift, and mutation played a role in the development of a variety of breeds, creating genetic variation between and within sheep populations. Genetic variation is a very important component in breeding as it allows breeding tools like selection to be applied in sheep improvement programs. Hailu & Getu (2015) pointed out that genetic diversity provides an opportunity for selection and animal improvement strategies. According to Notter (1999), genetic variation also enables animals to adapt to changing environmental conditions and enables some animals to survive in case of natural disasters. Also, diversity in animals is crucial for adaptation in different ecosystems, and this helps sustain the production level of different animals even in changing environmental conditions (Harkat *et al.*, 2015). Genetic variation enables breeders to respond to changing breeding objectives resulting from changes in consumer demands or preferences and changing environments because of global warming and climate change.

2.3 Phenotypic Characterization

Phenotypic characterization involves the identification and description of observable traits of a particular breed population, taking into consideration a variety of factors that may influence these traits (FAO, 2012). According to FAO (2012), phenotypic characterization provides an opportunity to determine the animal genetic resource status of various breeds and indicates if the genetic material is being eroded, hence providing early warnings to act and conserve those endangered breeds. Janssens & Vandepitte (2004) and Hailemariam *et al.* (2018) also indicated that phenotypic characterization provides body measurements that may be used as indicators for breed conservation, selection, and breed improvement strategies. As such, the information on observable attributes attaches value to the animals and makes it easy to select those that can be used as breeding stock (Aamir *et al.*, 2010). Phenotypic characterization covers both qualitative and quantitative traits of breed of interest as well as the production environment including management practices and demographic parameters of the farmers keeping the breeds of interest.

2.3.1 Qualitative traits

Qualitative traits are simply inherited attributes that are influenced by a single gene pair or at most a few genes. Even though they are not of economic importance like quantitative traits, they play a critical role in adaptive characteristics (FAO, 2012). These traits include coat color, presence and absence of horns, tail type, coat type, ear form, presence, and absence of wattle. According to a study carried out by Hailemariam *et al.* (2018) on indigenous sheep breeds of Ethiopia, it was found that the dominant color of the sheep was black, which was predicted to have helped the animals to adapt to the cold temperatures of the Gamogofa zone by absorbing solar radiation to regulate body temperatures. Karakul sheep is a native breed in Afghanistan and the area has a long winter season characterized by scarcity of feed resources (Musavi *et al.*, 2022). As such, the karakul sheep is characterized by long hair and a fat-tail, with the fat being utilized during the dry winter season.

2.3.2 Quantitative traits

Unlike qualitative traits, quantitative traits are complex and polygenic. They include all those body measurements of an animal that directly have a relationship (either positive or negative) with production traits, hence making them of economic importance. It is believed that traits like heart girth (HG), body length (BL), wither height (WH) and rump height (RH) can be used to estimate performance traits like body weight (BW) (Abera *et al.*, 2014). In a study carried out by Bolowe *et al.* (2021) on Tswana sheep, it was found that heart girth played a major role in the variation of body weight, hence making it a better predictor for animal body weight.

Quantitative traits are influenced by factors such as age (young or adult), sex (males, females, and castrates) and breed (FAO, 2012). Research has indicated a trend where most animal body measurements increased with an increase in age until a point of optimal maturity (Yoseph, 2007). Studies by Hailu *et al.* (2020) and Bolowe *et al.* (2021) indicated that most body measurements were significantly affected by the age of the animal in indigenous sheep breeds, hence an increase in age led to an increase in most linear body measurements. After optimal maturity is reached (usually 3 years of age), the body measurements start to decrease, but this trend does not affect body measurements like cannon bone length and head length (Hailu *et al.*, 2020). According to Mohammed *et al.* (2018), sex has a significant effect on most linear body measurements especially body weight, as high values are usually observed in males as compared to females. The same trend has been reported by several researchers in different breeds of sheep (Nsoso *et al.*, 2004; Harkat *et al.*, 2015; Michael *et al.*, 2016; Bolowe *et al.*, 2021). This trend may be caused by the differences in the endocrine system of males and females, as testosterone in males is believed to promote growth while estrogen limit growth in females (Baneh & Hafezian, 2009). Abera *et al.* (2014) however reported no significant sex effect in indigenous sheep breeds of the Selale area of Ethiopia which exhibited similar body measurements at similar ages.

2.4 Phenotypic Characteristics of common sheep breeds in Botswana

There are various sheep breeds found in Botswana which include those that are indigenous to Southern African countries (Tswana and Damara sheep), and those that are regarded as exotic as they originate from temperate areas (Karakul sheep). One of the most popular sheep breeds in Botswana after the native Tswana sheep, is the Dorper which is a composite breed developed in

South Africa (Masilo & Madibela, 2003). The most recent sheep breed to be introduced into the country is the meat-master which is a composite of the Dorper and Damara sheep breeds.

2.4.1 Tswana sheep

This is indigenous to Botswana, although it is not only found in Botswana as it has been found to exist in areas such as Zimbabwe and some regions of South Africa (Almeida, 2011). Tswana sheep are usually kept under small-scale communal systems with little investment in supplementary feeding, labor, and disease control (Baleseng *et al.*, 2016). The main purpose for keeping Tswana sheep is for subsistence purposes, where they provide the nutritional needs of the families in the form of meat and milk and sometimes emergency cash. The breed is better adapted to the harsh environmental conditions of Botswana, being able to utilize poor quality feed resources and tolerant to most local diseases and parasites (Nsoso *et al.*, 2004). This makes the breed to be utilized mostly by resource-poor farmers. The breed is also tolerant to changes in body weight that occur across the seasons. Aganga & Fabi (2007) indicated that even though the growth performance of Tswana sheep fluctuates with seasons, semi-intensive management system has the potential of improving the breed's performance. Tswana sheep is a medium-sized animal with an average mature body weight of 30-35 kg (average of males and females combined) under a communal free range management system and has a predominantly white coat color (Almeida, 2011). According to Bolowe *et al.* (2021), Tswana sheep is characterized by horizontal ears, short fat tails, and the absence of horns in both males and females.

2.4.1.1 Linear body measurements of Tswana sheep

There are some studies that have been carried out on linear body measurements of Tswana sheep, including that of Nsoso *et al.* (2004) close to two decades back, and the recent one by Bolowe *et al.* (2021) which focused only on the Southern districts of Botswana. All the studies were carried out under extensive management systems of Botswana. The following are linear body measurements of Tswana sheep as reported by Bolowe *et al.* (2021).

Table 2.1. Linear body measurements of Tswana sheep in Southern Districts of Botswana

Morphological Trait	Kgatleng	Kweneng	South-East	Southern	Mean

Body weight (BW) (kg)	37.41	34.14	34.94	38.93	36.36
Body length (BL) (cm)	62.56	61.36	62.18	63.18	62.32
Heart girth (HG) (cm)	78.72	77.24	78.06	81.00	78.76
Height at withers (HW) (cm)	64.69	64.59	66.28	65.62	65.30
Rump length (RL) (cm)	23.22	22.53	23.72	25.56	23.76
Rump height (RH) (cm)	64.46	64.20	65.91	65.70	65.12
Rump width (RW) (cm)	16.79	14.89	15.93	16.5	16.03
Tail length (TL) (cm)	34.92	35.77	35.52	33.25	34.87
Tail circumference (TC) (cm)	17.88	19.89	22.27	19.49	19.88
Head length (HL) (cm)	14.04	12.94	13.21	12.76	13.24
Head width (HDW) (cm)	11.11	9.55	10.61	9.24	10.13
Ear length (EL) (cm)	12.25	11.22	11.17	10.89	11.38
Shoulder width (SW) (cm)	22.77	21.73	23.11	21.79	22.35
Neck length (NL) (cm)	31.06	28.73	32.25	30.07	30.53
Canon bone length (CBL) (cm)	15.43	14.91	15.73	15.26	15.33
Canon bone circumference (CBC) (cm)	7.81	7.83	7.00	7.11	7.44
Scrotal circumference (SC) (cm)	26.09	28.12	24.27	24.50	25.75

Adapted from: Bolowe *et al.* (2021)

Bolowe *et al.* (2021) indicated a significant difference in body weight and most linear body measurements across the districts, which indicated within-breed variation in Tswana sheep. According to Agaviezor *et al.* (2012), variations in quantitative traits are a consequence of both genetic and environmental effects ($V_P=V_G+V_E$), hence animals in different locations are likely to perform differently. Body weight and linear body measurements of Tswana sheep were also mostly affected by age and sex (Nsoso *et al.*, 2004; Bolowe *et al.*, 2021).

2.4.2 Dorper sheep

Dorper sheep is a composite breed that was developed in South Africa from the Persian Black Head and the Dorset Horn breeds. The Dorper was developed to incorporate both the productive traits of the European breed (Dorset Horn) and the adaptive traits of the local breed (Persian Black Head) (Almeida, 2011). Ever since its development, Dorper sheep have been exported to different parts of the world including Namibia and Botswana. The breed has proved to be more adaptable to various environmental conditions ranging from semi-arid, dry, and temperate areas with acceptable production levels (Cloete *et al.*, 2000; Almeida, 2011). As an adaptive trait, Dorper sheep coat can be either hairy or woolly fleece and Cloete *et al.* (2000) have shown that this coat trait does not have any effect on the production performance of the breed. Furthermore, the Dorper has a better survival rate in drier areas with limited water resources, due to its ability to restore lost body weight when water is availed and better ability to withstand dehydration than European breeds (Cloete *et al.*, 2000).

The Dorper is a fast-growing breed that is characterized by early maturity, hence making it ideal for mutton production. (Cloete *et al.*, 2000). According to Selala & Tyasi (2022), the body weight of the Dorper has a positive relationship with other body measurements like body length, heart girth, withers height, rump height, and sternum height. This means that the body weight of Dorper sheep can be indirectly improved by selecting for these linear body measurements (Body length, heart girth, withers height, rump height, and sternum height). The ability of the breed to combine both adaptive and production traits has made it suitable for crossbreeding and the development of other composite breeds like the Meat-master, which is able to survive better in South African environmental conditions (Becker, 2021).

2.4.2.1 Reproductive performance

Dorper sheep is considered a breed that reaches sexual maturity early, the average age of the breed at first lambing has been reported to be 346 days (Cloete *et al.*, 2000). Literature indicates that at 7 months of age, the ewes have a fertility (Ewe fertility) of 58% while the rams have an increasing sperm concentration after 140 days of age, which shows potential to induce fertilization at an early age (Cloete *et al.*, 2000). Most studies indicate that mature (12 months) Dorper sheep have high ewe fertility of about 0.90 (fertility rate), which automatically leads to a high lambing rate (Cloete *et al.*, 2000; Becker, 2021).

2.4.2.2 Linear body measurements of Dorper sheep

Despite its popularity around the world, studies on phenotypic characterization of Dorper sheep in Southern Africa are still scarce, and only a few linear body measurements have been reported. Most literature focuses only on the production performance of the breed like sexual maturity, carcass traits, lambing and twinning, without taking into consideration specific body measurements that may directly or indirectly affect the production parameters. Table 2.2 below indicates some linear body measurements of the Dorper sheep breed from both Ethiopia and South Africa as reported by two different papers.

Table 2.2. Linear body measurements of Dorper sheep from Ethiopia and South Africa

Morphological trait	**Ethiopia** Mohammed *et al. (*2018)			**South Africa** Becker (2021)		
	Males	**Females**	**Mean**	**Males**	**Females**	**Mean**
Body weight (BW) (kg)	NONE	NONE	46.65	54.15	48.0	51.08
Body length (BL) (cm)	NONE	NONE	68.27	71.35	NONE	71.35
Heart girth (HG) (cm)	NONE	NONE	82.93	90.55	NONE	90.55
Height at withers (HW) (cm)	NONE	NONE	61.65	63.3	60.9	62.1
Rump length (RL) (cm)	NONE	NONE	20.76	23.4	20.4	21.9
Rump width (RW) (cm)	NONE	NONE	18.75	25.95	18.3	22.13
Head length (HL) (cm)	NONE	NONE	19.68	NONE	NONE	NONE

Chest width (CW) (cm)	NONE	NONE	NONE	23.66	21.5	22.58
Chest depth (CD) (cm)	NONE	NONE	25.68	28.7	29.1	28.9
Canon bone length (CBL) (cm)	NONE	NONE	11.80	NONE	NONE	NONE
Canon bone circumference (CBC) (cm)	NONE	NONE	NONE	NONE	NONE	NONE
Scrotal circumference (SC) (cm)	NONE	NONE	26.23	32.55	NONE	32.55

Adapted from Mohammed *et al.* (2018), and Becker (2021)

In another study, Mohammed *et al.* (2018) compared linear body measurements (body weight, body length, heart girth, rump length, rump width, head length, chest depth, canon bone length, and scrotal circumference) of the purebred Dorper sheep with those of Dorper crosses and the local Ethiopian breed and found that pure Dorper breed recorded the highest linear body measurements, followed by crosses and lastly the local breed, clearly indicating the superiority of the Dorper as a mutton producing breed and its preference in crossbreeding programs (Mohammed *et al.*, 2018). Fourie *et al.* (2002) found a strong positive correlation between heart girth and body weight in the Dorper, which indicated that selection for increased heart girth will result in improvements in the body weight of the Dorper breed.

2.4.3 Karakul sheep

Karakul sheep originates from Central Asia, and it is a native breed of north Afghanistan. The breed is believed to have been introduced into Southern African countries including Botswana in the twentieth century (Almeida, 2011). This breed plays a major role in the fashion industry due to the production of valuable fur and pelts from newborn lambs, especially the male lambs. Musavi *et al.* (2022) reported that the quality of pelts varies with age, with high-quality pelts being produced during the first four weeks of life and low-quality pelts after the fourth week. After the quality of the pelts deteriorates, the animals can then be utilized for other purposes like wool and mutton production (Musavi *et al.*, 2022). Karakul sheep is a fat-tailed breed that is well adapted to semi-arid and arid environmental conditions of Southern African countries like South Africa, Namibia, and Botswana. In Botswana, the breed is found predominantly in the Southern Kalahari where it provides diversity in agricultural products in the form of milk, pelts, and mutton (Nsoso & Madimabe, 2003).

Research on Karakul sheep is very limited and old, and mainly focused on the production characteristics of the breed and ignored the morphometric traits of the breed (Schoeman, 1998). In Botswana, Nsoso & Madimabe (2003) surveyed production constraints faced by Karakul sheep farmers in Southern Kalahari and reported a lack of extensive research on the breed and the potential of the breed in the country. Most recent research on morphological traits of the breed was done outside Africa. A study by Musavi *et al.* (2022) on the morphological traits of Karakul sheep in North Afghanistan gives a brief picture of both the qualitative and quantitative traits of the breed. It was found that the dominating coat colors of karakul sheep in North Afghanistan were black and grey. The long fat tail of the breed serves as an important adaptive trait, especially during long winters when there is limited pasture in mountainous areas of North Afghanistan (Musavi *et al.*, 2022).

Table 2.3. Linear body measurements of Karakul sheep in North Afghanistan

Morphological trait	Rams	Ewes
Body weight (BW) (kg)	47.6	44.3
Body length (BL) (cm)	45.5	45.1
Heart girth (HG) (cm)	83.4	80.4
Height at withers (HW) (cm)	67.3	66.4
Rump length (RL) (cm)	17.6	16.5
Head length (HL) (cm)	16.4	16.4

Adapted from Musavi *et al.* (2022)

Liner body measurements of Karakul sheep are influenced by both sex and age, with higher values reported in males than females, and four-year-old Karakuls having higher linear measurements than one-year-olds (Musavi *et al.*, 2022). This indicates an increase in morphometric traits of Karakul sheep as the animal advances in age.

2.4.4 Damara sheep

The Damara sheep originates from Namibia, and the modern Damara is believed to have descended from a fat-tailed indigenous breed that was kept by the Himba and Herero tribes in Namibia over centuries. The breed then spread to other Southern African countries like Botswana and South Africa. According to Du Toit (2008), Damara sheep have evolved over the years due to natural selection to better adapt and survive in the harsh desert environmental conditions without any veterinary assistance. This has made the breed develop unique characteristics that enable it to survive under a wide range of harsh environmental conditions.

2.4.4.1 Adaptations

The Damara sheep has good tolerance and high resistance to most local diseases and parasites, heat stress, and seasonal weight loss. The breed is characterized by long legs which enable it to travel long distances in search for pasture, and spiral horns in both sexes which act as a defense weapon during predator attacks (Almeida, 2011). Von Wielligh (2001) indicated that as compared to other sheep breeds, Damara sheep feed on various vegetation including grasses, shrubs, and bushes. Literature has indicated that Damara can be almost classified as a browser since about 60 percent (%) of its diet consists of browsing materials (Von Wielligh, 2001). Becker (2021) highlighted that Damara sheep can even browse the local invasive species, which makes the breed to be suitable for semi-arid and arid conditions where poor nutrition is usually experienced.

2.4.4.2 Reproductive performance

Sexual maturity in Damara sheep ranges from 10 to 12 months of age. As compared to the Dorper ewe, the Damara ewe's first lambing occurs at approximately 15 to 17 months of age (Almeida, 2011). The breed has a high fertility rate (89-95%) and lamb survival (96-98%), with twin lambing occurring at a frequency of 35% (Almeida, 2011). Kandiwa *et al.* (2019) found that even though Swakara (Karakul) and Damara sheep were cycling throughout the year, consistent progesterone (P4) levels were experienced in Damara sheep throughout all the seasons, while Swakara (Karakul) sheep exhibited fluctuations in P4 levels with a peak in autumn and the lowest levels in spring. Consistently high progesterone levels across seasons in the Damara point to non-seasonal breeding and lambing throughout the year.

2.4.4.3 Phenotypic characteristics

Despite the unique characteristics of the Damara, more interest is on composite breeds like the Dorper and Meat-master, hence there is very limited literature on the production and phenotypic characteristics of the Damara sheep. According to Almeida (2011), most of the information on the

Damara sheep is not published but only found in the breeders' private records. A recent study by Ngcobo e*t al.* (2022), highlighted only a few phenotypic characteristics of the Damara sheep breed like body weight, but the linear body measurements of the breed were not covered. Ngcobo e*t al.* (2022) reported the body weight of mature Damara rams and ewes of 61kg and 45kg, respectively, with an average weaning weight of 14.1 kg. The breed has a varied coat color, ranging from black, white, brown, and spotted or mixed colors (Almeida, 2011).

2.4.5 Meat-master sheep

Meat-master is a composite breed developed in South Africa from mainly the Dorper and Damara sheep breeds. Originally, the Meat-master breed was developed from crossing different sheep breeds like Dorper, Ile de France, South African Mutton Merino, Wiltshire Horn, Van Rooy and Damara. However, it was decided at the end by the breed society for Meat-master to have Dorper and Damara as their parent breeds (Becker, 2021). These two parental breeds were chosen because of their production (Dorper) and adaptive (Damara) traits, which allowed a balance for the Meat-master breed to produce more mutton even under low input extensive environments (Peter *et al.*, 2010). Meat-master inherited the ability to produce good carcass in a short period from Dorper, while the reproductive traits, strong herd instincts (enable it to hide from predators), limited veterinary services, resistance and tolerance to most Southern African diseases and parasites like most indigenous breeds was inherited from the Damara (Becker, 2011). In a study by Van der Merwe *et al.* (2020) which compared the lamb production of Dohne Merino, Dormer, Dorper, Meat-master, Merino, Namaqua Afrikaner, and South African Mutton Merino under feedlot production, it was found that Meat-master, Dorper and Namaqua Afrikaner took the shortest time as compared to their counterparts' breeds to reach market weight. This indicates that the Meat-master is a low input-and-high output, mutton breed that requires low maintenance and can reach peak production even under extensive production systems (Peter *et al.*, 2010). Meat-master is characterized by early reproduction maturation, with first lambing in ewes being around 15 months, which is like that of the Damara breed. However, Becker (2021) highlighted that Meat-master ewes can start lambing as early as 10 months of age.

2.4.5.1 Phenotypic characteristics

Literature on Meat-master is very scarce, despite the greater potential of the breed in Southern Africa. Studies like that of Peter (2011) focused on the production performance and how artificial selection has impacted the phenotype of the breed but to a lesser extent the linear body measurements of the breed. A recent study by Becker (2021) was able to expand more on the linear body measurements of the Meat-master breed, but the study was carried out on sheep breeds only found in South Africa. As such, there was no literature found on Meat-master sheep found in Botswana. To get a better understanding of the morphometric traits of the Meat master, results from Becker (2021) were used to construct Table 2.4.

Table 2.4. Linear body measurements of Meat-master sheep in South Africa

Morphological trait	**Ram**	**Ewes**
Body weight (BW) (kg)	80.47	57.51
Body length (BL) (cm)	78.95	72.67
Heart girth (HG) (cm)	102.45	92.95
Height at withers (HW) (cm)	63.91	58.99
Rump length (RL) (cm)	21.82	20.77
Head length (HL) (cm)	23.93	22.68
Neck length (NL) (cm)	28.35	29.61
Tail length (TL) (cm)	38.24	36.64

Adapted from Becker (2021)

2.5 Estimation of body weight using linear body measurements

Morphometric traits help provide a clear picture of the variation in size and conformation of different animals (Castillo *et al.*, 2023). Body weight has been shown by literature to be the primary production trait compared to other quantitative traits as it determines most livestock management practices like feeding, vaccination, slaughter time and evaluation of growth (Rotimi *et al.*, 2020; Ibrahim *et al.*, 2020). A positive correlation has been established between body weight and most linear body measurements such as heart girth, body length, height at withers and rump height, with heart girth having the highest association with body weight in indigenous Zulu and Tswana sheep (Mavule, 2012, and Bolowe *et al.*, 2021, respectively). On the other hand, Rotimi *et al.* (2020) found the highest correlation between body weight and height at withers in female Sahelian goats. As such these traits (heart girth, body length, height at withers and rump height) can be used to estimate body weight. Kunene (2010) indicated that generally, the correlation between body weight and other linear body measurements is weaker in females as compared to their male counterparts. This indicates that the relationship between body weight and linear body measurements varies across sex. The interrelationships and correlations between body weight and morphometric traits are essential in determining the genetic potential and breeding programs (Younas *et al.*, 2013). According to Mohammed *et al.* (2018), correlations between morphometric traits aid breeders during selection to be aware of positively and negatively related traits. This makes it easier for breeders to take advantage of traits that are positively correlated and avoid the effects of negative correlations during selection.

Weighing scales are usually used to measure the body weight of farm animals, but their high cost and maintenance make them unavailable to small-scale resource-poor farmers who end up relying on visual observations (Temoso *et al.*, 2017). Body weight is a very important parameter in rural areas as it determines the market and sale price of the animals especially in Botswana when selling to local butcheries (Sebolai *et al.*, 2012). This means that accurate body weight measurements are crucial. Instead of using expensive weighing scales, other methods which are cost-effective and easier to use under field conditions with limited resources like prediction equations can be utilized to estimate body weight (Mahmud *et al.*, 2014). Prediction equations can be developed from various independent linear body measurements which are strongly and positively correlated to the dependent variable (body weight). Heart girth has been found by Baleseng *et al.* (2016), Temoso *et al.* (2017), Mohammed *et al.* (2018) and Bolowe *et al.* (2021) to be the best body weight predictor in sheep. Kunene (2010) reported that the scrotal circumference of young Zulu rams which are under 22 months of age can be used to reliably estimate the body weights of these animals. However, Abera *et al.* (2014) and Michael *et al.* (2016) indicated that high level accurate body weight can be predicted from more than one independent trait like heart girth, body length and height at withers. Getachew *et al.* (2009) highlighted that even though adding more independent variables to the prediction equation results in accurate estimations of body weight, the simplicity of the equation should also be considered. This is because under field conditions, animal handling may be difficult and more errors may be incurred when measuring traits that are affected by animal posture (body length, rump height, and height at withers). Taking linear body measurements like height at withers and body length therefore, requires animal handling skills to maintain the correct animal posture for accurate measurements. Also, for accurate results to be obtained, the farmer should know exactly where to place the measuring tape or ruler, which may be a challenge for elderly small-holder farmers. As such traits like heart girth which have a higher correlation with body weight may be used as the sole predictor of sheep body weight to reduce chances of error (Getachew *et al.*, 2009). According to Baffour-Awuah *et al.* (2000) and Bolowe *et al.* (2021), heart girth is considered the most simple and easily measurable variable as compared to other linear body measurements (body length and height at withers). This indicates that various prediction equations for different breeds, sex, age, and management environments should be developed (Younas *et al.*, 2013).

2.6 Summary

A review of the literature indicated that there are limited studies on phenotypic characterization of sheep breeds found in Southern Africa, especially in Botswana. Most studies on Dorper and Meat-master sheep breeds focused on the production performance of these animals and not their morphological traits or linear body measurements. However, morphological traits are crucial for phenotypic characterization, which aid in development of breed improvement programs and determine the genetic status of various sheep breeds. Studies on phenotypic characterization of Tswana breed have been carried out under extensively managed systems, while those for Dorper, Meat-master, Karakul, and Damara have been done outside Botswana. Since different management practices and environmental conditions influence animal performance, it is therefore essential to carry studies on phenotypic characterization of various sheep breeds under Botswana conditions and different management systems.

2.7 References

Aamir, H.M., Babiker, S.A., Youssif, G.M., & Hassan, Y.A. (2010). Phenotypic characterization of Sudanese Kenana cattle. *Research Journal of Animal Veterinary Science,* 5, 43-47.

Abera, B., Kebede, K., Gizaw, S., & Feyera, T. (2014). On-Farm Phenotypic Characterization of Indigenous Sheep Types in Selale Area, Central Ethiopia. *Veterinary Science and Technology, 5* (3), 1-6.

Aganga, A.A., & Fabi, L. (2007). Performance of Tswana Sheep under Semi-Intensive Management in Gaborone, Botswana. *Research Journal of Animal Sciences, 1* (4), 123-127.

Agaviezor, B.O., Peters, S.O., Adefenwa, M.A., Yakubu, A., Adebambo, O.A., Ozoje, M.O., Ikeobi, C.O.N., Wheto, M., Ajayi, O.O., Amusan, S.A., Ekundayo, O.J., Sanni, T.M., Okpeku, M., Onasanya, G.O., Donato, M.D., Ilori, B.M., Kizilkaya, K., & Imumorin, I. (2012). Morphological and microsatellite DNA diversity of Nigerian indigenous sheep. *Journal of Animal Science and Biotechnology, 3* (38), 1-16.

Almeida, A.M. (2011). The Damara in the context of Southern Africa fat-tailed sheep breeds. *Tropical Animal Health Production,* 43, 1427-1441.

Baffour-Awuah, O., Ampofo, E., & Dodoo, R. (2000). Predicting the live weight of Sheep by using linear body measurements. *Ghana Journal of Agricultural Science,* 33, 207-212.

Baleseng, L., Kgosikoma, O.E., & Makgekgenene, A. (2016). Performance of goats and sheep under communal grazing in Botswana using various growth measures. *Rome,* 1-7.

Baneh, H., & Hafezian, S. H. (2009). Effect of environmental factor on growth traits in Ghezel sheep. *African Journal of Biotechnology,* 8, 2903-2907.

Becker, S.J. (2021). Phenotypic characterisation of Meatmaster sheep using quantitative and qualitative trait analysis. *Masters thesis.* Central University of Technology. Free State, South Africa.

Bolowe, M.A., Thutwa, K., Kgwatalala, P.M., Monau, P.I., & Malejane, C. (2021). Phenotypic characterization of indigenous Tswana sheep population in selected Districts of Southern Botswana. *African Journal of Agricultural Research, 17* (10), 1268-1280.

Castillo, P.E., Macedo, R.J., Arredondo, V., Zepeda, J.L., Valencia-Posadas, M., & Haubi, C.U. (2023). Morphological Description and Live Weight Prediction from Body Measurements of Socorro Island Merino Lambs. *Animals,* 13, 1-11.

Cloete, S.W.P., Snyman, M.A., & Herselman, M.J. (2000). Productive performance of Dorper sheep. *Small Ruminant Research,* 36, 119-135.

Du Toit, D.J. (2008). The indigenous livestock of Southern Africa. https://www.damarasheep.co.za/files/ParisRoundatable.pdf.

FAO. (2012). *Phenotypic characterization of animal genetic resources*. FAO Animal Production and Health Guidelines No. 11. Rome.

Fourie, P.J., Neser, F.W.C., Olivier, J.J., & Van der Westhuizen, C. (2002). Relationship between production performance, visual appraisal and body measurements of young Dorper rams. *South African Journal of Animal Science, 32* (4), 256-262.

Getachew, T., Haile, A., Tibbo, M., Sharma, A.K., Sölkner, J., Wurzingere, M., & Terefe, E. (2009). Use of linear body measurements for performance recording and genetic evaluation of Menz and Afar sheep breeds under village condition. *Ethiopian Society of Animal Production,* 17, 114-121.

Hailemariam, F., Gebremicheal, D., & Hadgu, H. (2018). Phenotypic characterization of sheep breeds in Gamogofa zone. *Agriculture and Food Security, 7* (27), 1-7.

Hailu, A., & Getu, A. (2015). Breed Characterization: Tools and Their Applications. *Open Access Library Journal,* 2: e1438.

Hailu, A., Mustefa, A., Aseged, T., Assefa, A., Sinkie, S., Tsewene, S. (2020). Phenotypic characterization of sheep populations in Tahtay Maichew district, Northern Ethiopia. *Genetic Resources, 1* (2), 12-22.

Hanotte, O., Bradley, D. G., Ochieng, J. W., Verjee, Y., Hill, E. W., & Rege, J. E. O. (2002). African pastoralism: Genetic imprints of origins and migrations. *Science,* 296, 336-339.

Harkat, S., Laoun, A., Benali, R., Outayeb, D., Ferrouk, M., Maftah, A., Da Silva, A., &Lafri, M. (2015). Phenotypic characterization of major sheep breed in Algeria. *Revenue Medical Veterinary, 166* (6), 138-147.

Henshilwood, C. (1996). A revised chronology for pastoralism in southermost Africa: New evidence of sheep at c. 2000 b.p. from Blombos Cave, South Africa. *Antiquity,* 70, 945-949.

Ibrahim, A., Budisatria, I.G.S., Widayantim, R., Atmoko, B.A., Yuniawan, R., & Artama, W.T. (2020). On-farm body measurements and evalution of Batur Sheep on different age and sex in Banjarnegara District, Indonesia. *Advances in Animal Veterinary Science,* 8, 1028-1033.

Janssens, S., & Vandepitte, W. (2004). Genetic parameters for linear measurements and linear type traits in Belgian Bleu du Maine, Suffolk and Texel sheep. *Small Ruminants Research,* 54, 13-24.

Kandiwa, E., Mushonga, B., Madzingira, O., Samkange, A., Bishi, A., & Tuaandi, D. (2019). Characterizaion of Oestrus Cycles in Namibian Swakara and Damara Sheep through Determination of Circannual Plasma Progesterone Levels. *Journal of Veterinary Medicine,* 18, 1-6.

Kunene, N.W. (2010). Characterization of indigenous Zulu (Nguni) sheep for utilization, improvement and conservation. *Doctor of Philosophy Dissertation*. University of KwaZulu-Natal, South Africa.

Mahmud, M.A., Shaba, P., Abdulsalam, W., Yisa, H.Y., Gana, J., Ndagi, S., & Ndagimba, R. (2014). Live body weight estimation using cannon bone length and other body linear measurements in Nigerian breeds of sheep. *Journal of Advanced Veterinary and Animal Research, 1* (4), 169-176.

Masilo, B.S., & Madibela, O.R. (2003). *Report on the State of the World Animal Genetic resources (AnGR): Botswana Country Report*. Gaborone, Botswana: Agricultural Research.

Mavule, B.S. (2012). Phenotypic characterization of Zulu sheep: Implications for conservation and improvement. *Masters Dissertation*. University of Zululand, South Africa.

Michael, A., Kefelegn, K., & Yoseph, M. (2016). Phenotypic Characterization of Indigenous Sheep Types in Northern Ethiopia. *Journal of Natural Sciences Research, 6* (15), 16-27.

Mohammed, J., Abegaz, S., Lakew, M., & Tarekegn, G.M. (2018). Phenotypic Characterization of Dorper, Local Sheep and Their Crossbred Sheep Population in North Eastern Amhara, Ethiopia. *Journal of Biology, Agriculture and Healthcare, 8* (1), 15-25.

Moradi, M. H., Nejati-Javaremi, A., Moradi-Shahrbabak, M., Dodds, K. G., & McEwan, J. C. (2012). Genomic scan of selective sweeps in thin and fat tail sheep breeds for identifying of candidate regions associated with fat deposition. *BMC Genetics*, 13, 10. doi:10.1186/1471-2156-13-10.

Muigai, A.W.T., & Hanotte, O. (2013). The Origin of African Sheep: Archaeological and Genetic Perspectives. *African Archaeology Review,* 30, 39-50.

Musavi, S. A. A., Khadimiyan, A. M., & Azimi, A. M. (2022). Morphological Characterization of Karakul Sheep in North Part of Afghanistan. *Voice of the Publisher,* 8, 16-25.

Ngcobo, J.N., Nedambale, T.L., Nephawe, K.A., Mpofu, T.J., Chokoe, T.C., & Ramukhithi, F.V. (2022). An Update on South African Indigenous Sheep Breeds' Extinction Status and Difficulties during Conservation Attempts: A Review. *Diversity,* 14, 516.

Notter, D.R. (1999). The Importance of Genetic Diversity in Livestock Populations of the Future. *Journal of Animal Science,* 77, 61-69.

Nsoso, S.J., & Madimabe, M.J. (2003). A survey of Karakul sheep farmers in Southern Kalahari, Botswana: management practices and constraints to improving production. *South African Journal of Animal Science,* 4, 23–27.

Nsoso, S.J., Podisi, B., Otsogile, E., Mokhutshwane, B.S., & Ahmadu, B. (2004). Phenotypic Characterization of Indigenous Tswana Goat and Sheep Breeds in Botswana: Continuous Traits. *Tropical Animal Health and Production,* 36, 789-800.

Peter, F.W. (2011). Meatmaster sheep breed establishment in South Africa. Kenjafa Knowledge Works.

Peter, F.W., Kotze, A., Van der Bank, F.H., Soma P., & Grobler, J.P. (2010). Genetic profile of the locally developed Meatmaster sheep breed in South-Africa based on microsatellite analysis. *Small Ruminant Research,* 90, 101-108.

Rotimi, E.A., Momoh, O.M., & Egahi, J.O. (2020). Relationship between bodyweight and morphological traits in Sahelian goats of Nigeria using path analysis. *Journal of Agricultural Sciences, 25* (3), 455-460.

Schoeman, S.J. (1998). Genetic and environmental factors influencing the quality of pelt traits in Karakul sheep. *South African Journal of Animal Science, 28* (3/4), 125-139.

Sebolai, B., Nsoso, S. J., Podisi, B., & Mokhutshwane, B. S. (2012). The estimation of live weight based on linear traits in indigenous Tswana goats at various ages in Botswana. *Tropical Animal Health Production, 44* (4), 899-904.

Selala, L.J., & Tyasi, T.L. (2022). Using Morphological Traits to Predict Body Weight of Dorper Sheep Lambs. *World Veterinary Journal, 12* (1), 66-73.

Temoso, O., Coleman, M., Baker, D., Morley, P., Baleseng, L., Makgekgenene, A., & Bahta, S. (2017). Using path analysis to predict body weight from body measurements of goats and sheep of communal rangelands in Botswana. *South African Journal of Animal Science, 47* (6), 854-863.

Van der Merwe, D.A., Brand, T.S., & Hoffman, L.C. (2020). Premium lamb production of South African sheep breed types under feedlot conditions. *South African Journal of Animal Science, 50* (4), 578-587.

Von Wielligh, W. (2001). The Damara Sheep as Adapted Sheep Breed in Southern Africa, Community-based Management of Animal Genetic Resources Congress. *Food and Agriculture Organization of the United Nations.* Mbabane, Swaziland, 173–175.

Yoseph, M. (2007). Reproductive traits in Ethiopian male goats: With special reference to breed and nutrition. *Doctoral thesis*. Swedish University of Agricultural Sciences. Uppsala, Sweden.

Younas, U., Abdullah, M., Bhatti, J.A., Pasha, T.N., Ahmad, N., Nasir, M., & Hussain, A. (2013). Inter-relationship of body weight with linear body measurements in Hissardale sheep at different stages of life. *Journal of Animal and Plant Sciences,* 23, 40-44.

CHAPTER 3

Phenotypic characterization of Tswana, Dorper, Damara, Meat-master and Karakul sheep breeds

3.1 Abstract

The aim of the study was to phenotypically characterize Tswana, Dorper, Damara, Meat-master, and Karakul sheep breeds under the ranch management system in Botswana. Qualitative and quantitative traits were determined/measured from a total of 595 randomly sampled adult sheep population (one year old and above). The sample size was determined by the sheep populations found at the study site. Statistical Analysis System (SAS) version 9.4 was used to analyze quantitative data (body weight and linear body measurements) in a model that included fixed effects of breed and sex and the interaction between breed and sex. Qualitative data was analyzed using Frequency (FREQ) procedures of SAS. Damara and Meat-master were characterized by brown coat color and straight long fat and moderate tails, respectively. Dorper and Karakul breeds have plain coat color pattern with Dorper having black head and white body while Karakul have black coat color. A patchy coat color pattern with predominantly white color characterized Tswana sheep. Breed and sex significantly ($p<0.05$) influenced body weight and most linear body measurements, with males being heavier across all the breeds than females. Meat-master rams were the heaviest (73.8±1.60 kg), followed by Karakul (70.2±4.65 kg), Dorper (68.9±1.52 kg), Damara (55.5±1.98 kg), and lastly, Tswana (49.3±5.70 kg), while Dorper ewes were the heaviest (59.0±1.12 kg), followed by Meat-master (57.5±1.15 kg), Karakul (52.4±1.02 kg), Damara (51.7±1.72 kg) and lastly Tswana (39.2±1.98 kg). Meat-master, Dorper, and Karakul rams had significantly ($p<0.05$) higher body length, heart girth, head width and ear width than their indigenous counterparts (Tswana and Damara). There were no significant ($p>0.05$) differences between Damara and Tswana rams in body weight, heart girth, ear width and rump width. Dorper ewes had significantly ($p<0.05$) higher body length, shoulder width, and rump width than ewes of other breeds. Body weight, heart girth, and height at withers were significantly ($p<0.05$) higher in Damara and Meat-master castrates than Dorper, Karakul, and Tswana castrates. This indicates variation across breeds, which may aid in breed improvement programs.

Keywords: Breed, linear body measurements, sex

3.2 Introduction

Sheep play an important role in the socio-economic and socio-cultural livelihoods of people living in rural areas (Aganga & Aganga, 2015). Sheep are a source of meat which provides food security to farmers. However, the sheep population is smaller with an estimate of 227 247 as compared to the goat population in Botswana (1 605 642) (Statistics Botswana, 2016). There are various sheep breeds found in Botswana including Tswana, Dorper, Damara, Meat-master and Karakul, but the indigenous Tswana sheep constitute the majority of the Botswana sheep population (Baleseng *et al.*, 2016). This is because Tswana sheep are more adapted to harsh Botswana environmental conditions by being tolerant to local diseases and parasites, while on the other hand being able to utilize limited poor feed resources (Nsoso *et al.*, 2004). However, Tswana sheep lack the required economic traits for meat production. As a result, farmers have introduced other breeds such as Dorper and Meat-master to improve meat production. This makes it essential to carry out phenotypic characterization of these introduced sheep breeds to monitor their performance under the local Botswana environment. According to Janssens *et al.* (2004), animal morphological traits can be used in genetic improvement programs and selection.

Several studies on the phenotypic characterization of Dorper (Mohammed *et al.*, 2018; Selala & Tyasi, 2022), Karakul (Musavi *et al.* 2022), and Meat-master (Becker, 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 breed 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). As for the phenotypic characterization of the indigenous Tswana sheep breed, studies exist (Nsoso *et al.*, 2004; Bolowe *et al.*, 2021), but all these studies were carried out under extensively managed farms where animals depended only on grazing of rangelands unlike ranch managed animals which are provided with supplementary feed throughout the year. As a result, the aforementioned studies on Tswana sheep may not give a reflection of what is happening in ranches.. As such it is 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. Therefore, the aim of this study was to phenotypically characterize the Tswana, Dorper, Karakul, Meat-master, and Damara sheep breeds under the ranch management system.

3.3 Materials and Methods

3.3.1 Study site

The study was carried out from March 2023 to June 2023 at Lobu field station and Botswana University of Agriculture and Natural Resources (BUAN) research farm. The BUAN farm is found in the South-East district of Botswana and the area is characterized by a semi-arid climate. Lobu field station is located South-West of Botswana in the Kgalagadi South district (26°35’13’S 21°49’02’E). Lobu farm is about 110 km from Tsabong village and 10 km from a small village called Khuis. Kgalagadi area is characterized by low summer rainfalls with an average rainfall of 300mm per annum, which contributes to extreme temperatures ranging from 29 to 35 degrees Celsius during summer and from 1 to 12 degrees Celsius during winter (Seifu *et al.*, 2019). Kgalagadi region is believed to have the longest dry season which can go up to 6 months (April – October). The research area is an arid savannah woodland and grassland, with sparsely distributed vegetation and various grass species (Kgaudi, 2014).

3.3.2 Study animals

The animals used for the study were randomly sampled from different sheep breed populations found in the study areas, and a total of five hundred and ninety-five (595) sheep were sampled from five sheep breeds including Damara (44 females and 35 males), Dorper (105 females and 72 males), Karakul (126 females and 9 males), Meat-master (98 females and 58 males) and Tswana (33 females and 15 males). The sample size was determined by the sheep populations found at the study site. Each sheep was visually identified and categorized into different breeds (Tswana, Dorper, Karakul, Meat-master and Damara), sex (males, females, and castrates) and age (one year and above). The age of the sheep was determined through the dentition procedure described by Wilson & Durkin (1984). Only dry (non-pregnant) adult animals were sampled in females (1PPI and above).

3.3.3 Data collection

Qualitative traits were visually observed, and quantitative traits were measured from a total of 595 sheep (Tswana, Dorper, Damara, Meat-master and Karakul), following the breed morphological characteristics descriptor list for phenotypic characterization of sheep by FAO (2012). Qualitative traits that were observed included coat color, coat form, horn (presence or absence), horn shape, ear orientation, tail type, tail form, and wattle. A flexible measuring tape was used to measure quantitative traits like 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), scrotal circumference (SC) in males. A weighing band was used to estimate the body weight (BW) of the sampled sheep populations. The animals were put in an upright position during handling and allowed to relax before taking measurements.

3.3.4 Statistical analysis

Data on qualitative traits and quantitative linear body measurements was analyzed using Frequency (FREQ) and General Linear Model (GLM) procedures, respectively, of Statistical Analysis System (SAS, release 9.4 2013). GLM procedures were used to determine least square means and standard errors of body weight and all other morphometric traits. The means were tested at a significance level of 5% (0.05). Breed and sex were fitted as independent variables while body weight and linear body measurements (except scrotal circumference) were fitted as dependent variables. The scrotal circumference in rams was analyzed by fitting breed as an independent variable, while the scrotal circumference was treated as a dependent variable. The following are the models that were used for the analysis of quantitative traits of the sampled sheep populations:

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

$Y_{ij} = \mu + B_i + S_j + (BxS)_{ij} + e_{ij}$

Where; Y_{ij} = body weight or measured linear body measurements

μ = overall population mean

B_i = the fixed i^{th} breed effect

S_j = the fixed j^{th} sex effect

$(BxS)_{ij}$ = the interaction effect of i^{th} breed and j^{th} sex

e_{ij} = random error

Model for mean square analysis of scrotal circumference

$Y_i = \mu + B_i + e_i$

Where; Y_i = measured scrotal circumference

μ = overall population mean

B_i = the fixed i^{th} breed effect

e_i = random error

3.4 Results and Discussion

3.4.1 Qualitative traits of different sheep breeds

There were variations in most qualitative traits across the different sheep breeds, with the predominant coat color pattern being plain for the four sheep breeds (Damara: 66.7%, Dorper: 96.6%, Karakul: 100%, Meat-master: 64.1%) except the Tswana where patchy coat color pattern was predominant (Table 3.1). The patchy coat color pattern in Tswana sheep is in contrast with Bolowe *et al.* (2021) who found plain coat color to be predominant in Tswana sheep breeds of Southern Botswana. This discrepancy could be due to the fact that Tswana sheep in the study by Bolowe *et al.* (2021) were extensively managed and had greater chances of interbreeding with other populations, hence the enhanced diversity whereas Tswana sheep in the current study were from a closed population where there is no interbreeding and hence reduced diversity in coat color. Also, this may be a result of selection for different coat color patterns by farmers. However, Bolowe *et al.* (2021) reported a high percentage of Tswana sheep with white dominant coat color, which is like the findings of the current study (Figure 3.5). This could be an adaptive trait to the environmental conditions of Botswana as the white color helps the animal to survive better in hot temperatures. The majority of Karakul sheep had predominantly black coat color with long smooth hair type (Figure 3.4) and this is consistent with Hailemariam *et al.* (2018) who reported a high percentage of black coat color in sheep found in the Gamogofa zone. Black coat color helps animals in cold areas to absorb enough solar radiation which helps in body heat regulation (Hailemariam *et al.*, 2018). Brown coat color was common in Damara (54.8%) and Meat-master (61.5%) sheep breeds while the predominant coat color for Dorper was white body and black head (96.6%). The brown coat color in Damara and Meat-master could be an adaptive trait to help the animals survive better in desert areas by being able to camouflage with the sandy landscape and elude predation. Contrary to the current findings, Becker (2021) reported red and white coat color to be common in the Meat-master sheep breed of South Africa. This shows that there are different coat color variations in Meat-master breed, which may be location specific or influenced by the environment that they occupy for better survival.

Damara and Meat-master were the only sheep breeds where 100% of the sampled animals were not docked. From the current findings, the Damara tail can be characterized as long fat with a straight tip (Figure 3.1) while the Meat-master tail can be characterized as moderate with a straight tip (Figure 3.3) and this is consistent with Abera *et al.* (2014) who reported long fat tail with a straight tip for indigenous sheep breeds in Selale area of Ethiopia. Semi-pendulous ears were common in Damara, Meat-master and Tswana sheep breeds and this was similar to Abera *et al.* (2014) who found semi-pendulous ears to be predominant in Ethiopian indigenous sheep breeds. To the contrary, Bolowe *et al.* (2021) reported horizontal ears to be common in Tswana sheep found in Southern Districts of Botswana, and this might be attributed to the diverse genetic background of Tswana sheep, together with the environment they are found in. According to Becker (2021), each individual animal has its unique genotype and phenotype, and the phenotype is influenced by the environment to enable production and survival in a certain area. Dorper sheep had horizontal ears while Karakul sheep had pendulous ears. All the breeds were polled except for the Damara and the Karakul. The horn shape that was common in the Damara was spiral (52.4%), followed by curved (21.4%) and this is consistent with Almeida (2011) who reported predominantly spiral horns for Damara irrespective of sex.

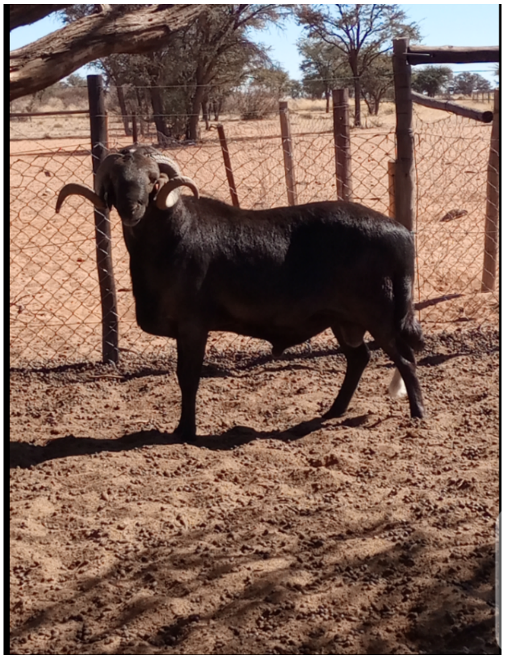

Figure 3.1 a) Damara ram

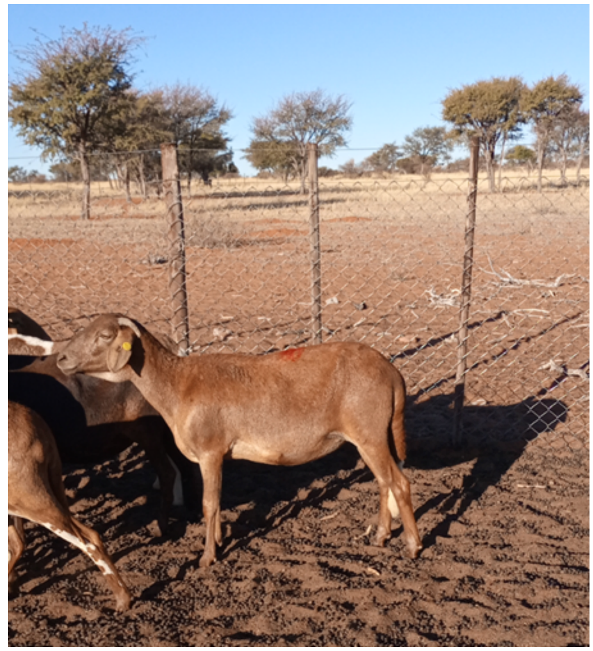

Figure 3.1 b) Damara ewe

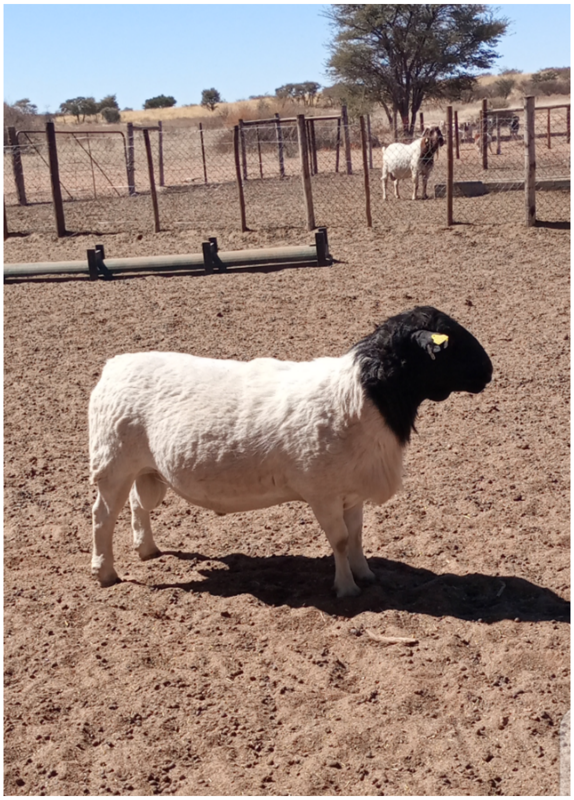

Figure 3.2 a) Dorper ram

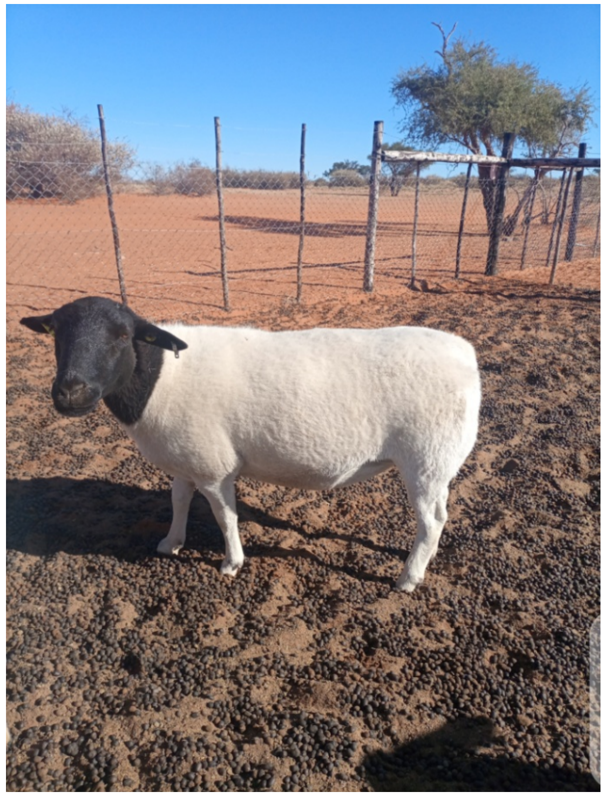

Figure 3.2 b) Dorper ewe

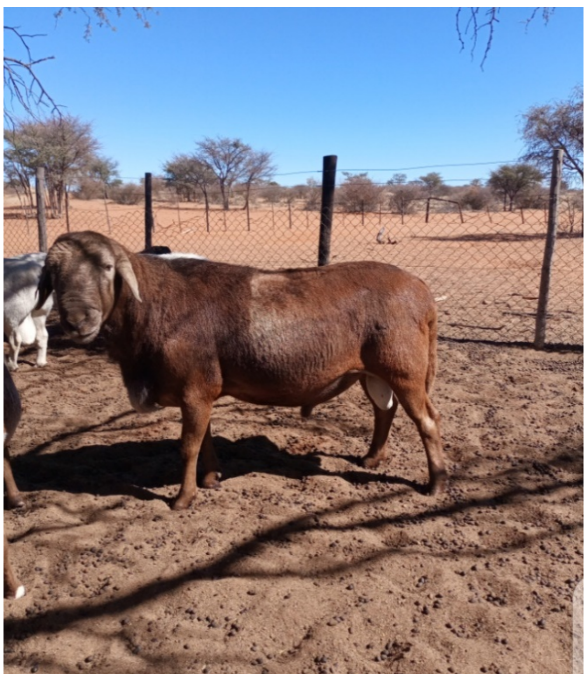

Figure 3.3 a) Meat-master ram

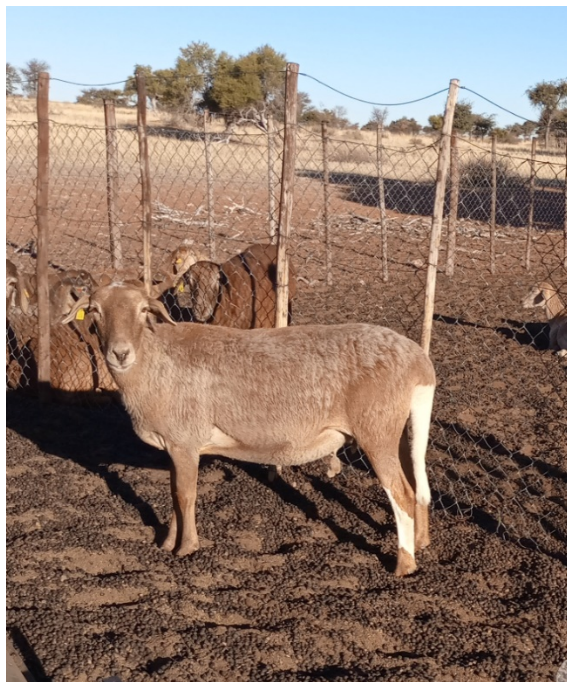

Figure 3.3 b) Meat-master ewe

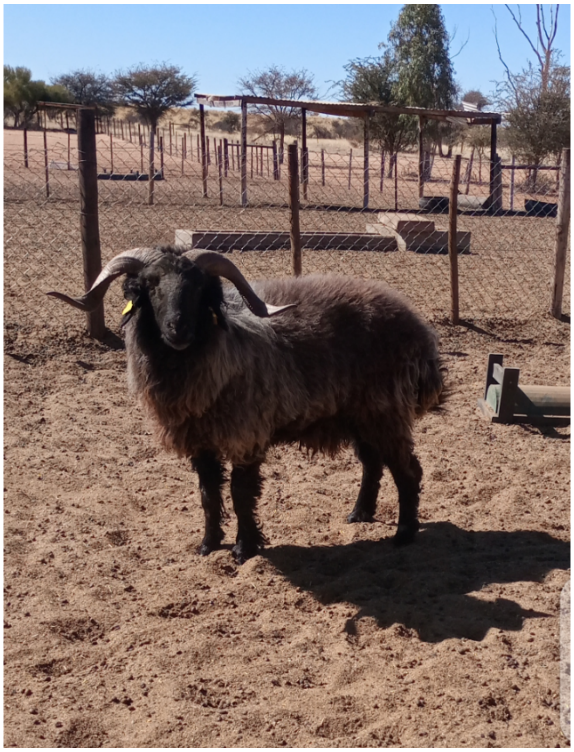

Figure 3.4 a) Karakul ram

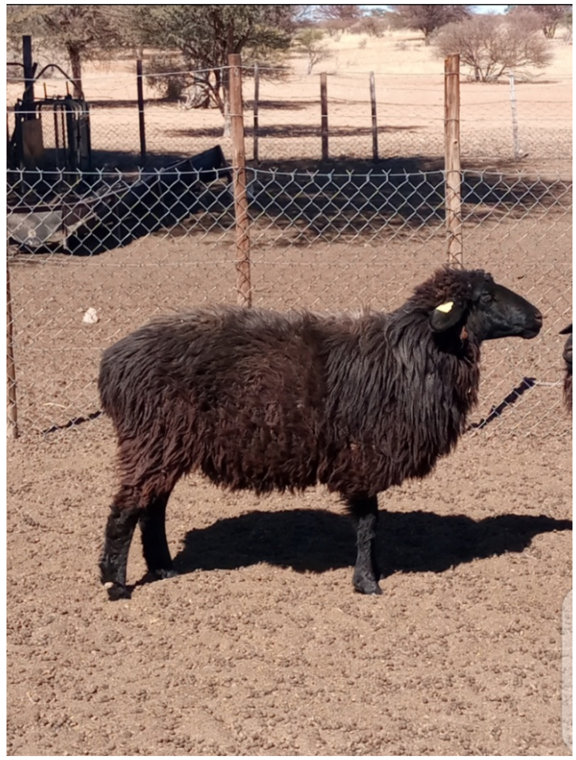

Figure 3.4 b) Karakul ewe

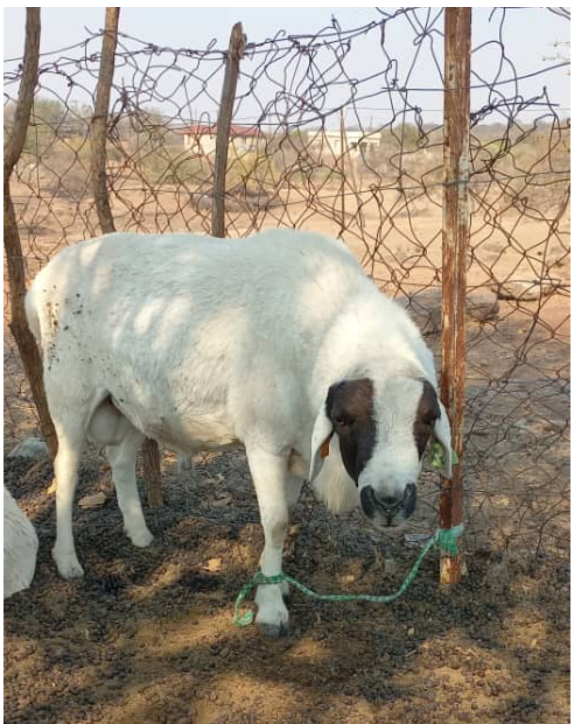

Figure 3.5 a) Tswana ram

Figure 3.5 b) Tswana ewe

Table 3.1. 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	NONE	NONE	NONE	12.8	66.7
Spotted	33.3	3.4	NONE	23.1	18.8
Coat color type					
White	NONE	NONE	NONE	1.3	14.6
Black	11.9	NONE	70.4	0.6	NONE
Brown	54.8	NONE	NONE	61.5	NONE
White body, black head	NONE	96.6	2.22	NONE	NONE
Grey body, black head	NONE	NONE	27.4	NONE	NONE
White dominant	4.76	3.4	NONE	16	79.2
Black dominant	2.38	NONE	NONE	2.6	4.2
Brown dominant	26.2	NONE	NONE	17.3	2.1
Hair type					
Short and smooth	100	100	NONE	100	16.7
Long and smooth	NONE	NONE	99.3	NONE	NONE
Long and coarse	NONE	NONE	0.74	NONE	6.3
Short and coarse	NONE	NONE	NONE	NONE	75
Tail type					
Short fat	NONE	NONE	6.7	NONE	4.2
Long fat	100	NONE	NONE	NONE	NONE
Short thin	NONE	NONE	NONE	NONE	4.2
Long thin	NONE	NONE	NONE	NONE	NONE
Long moderate	NONE	NONE	NONE	100	NONE
Docked	NONE	100	93.3	NONE	91.7
Tail form					
Curved at tip	NONE	NONE	NONE	NONE	NONE
Straight at tip	100	NONE	6.7	100	8.3
Docked	NONE	100	93.3	NONE	91.7
Ear form					
Horizontal	NONE	100	NONE	NONE	20.8
Semi-pendulous	100	NONE	6.7	100	68.8
Pendulous	NONE	NONE	93.3	NONE	10.4
Erect	NONE	NONE	NONE	NONE	NONE
Wattle					
Present	NONE	NONE	NONE	NONE	NONE
Absent	100	100	100	100	100
Horn					
Present	73.8	NONE	5.2	1.3	6.3
Absent	26.2	100	94.8	98.7	93.7
Horn shape					
Straight	NONE	NONE	1.5	NONE	2.1
Curved	21.4	NONE	3	1.3	2.1
Spiral	52.4	NONE	0.7	NONE	NONE
Scurs	NONE	NONE	NONE	NONE	2.1

3.4.2 Effects of sex on quantitative traits within breeds

Body weight and most linear body measurements were significantly ($p<0.05$) influenced by sex in all the five sheep breeds (Table 3.2) and this is consistent with Mohammed *et al.* (2018) who reported a similar trend in Dorper, Dorper crosses and local Ethiopian sheep breeds. The difference in body weight and most morphological traits between males (rams and castrates) and females of the different sheep breeds indicate 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). Body weight, heart girth, tail circumference and rump height of Damara castrates were significantly ($p<0.05$) higher than that of rams and ewes. This may be because Damara castrates used in the study had more mature age groups (2 years old and above), unlike Damara rams amd ewes which included one-year old age group. However, body weight, heart girth, rump height, rump width, shoulder width, head width and cannon bone length for Dorper, Karakul and Meat-master sheep breeds were significantly ($p<0.05$) higher in rams than their female counterparts. Consistent with the current findings, Selala & Tyasi (2022) and Musavi *et al.* (2022) reported significantly higher body weight and most linear body measurements in males of Dorper and Karakul breeds than their female counterparts, respectively. 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) for Dorper and Karakul rams, respectively.

There were no significant ($p>0.05$) differences between ewes and castrates of Dorper and Karakul breeds for body weight, heart girth, head width, cannon bone circumference and cannon bone length. However, Damara and Meat-master sheep breeds had significantly ($p<0.05$) higher height at withers and rump width in males (rams and castrates) than ewes. This is consistent with Mavule (2012) who reported a significant difference between males and females of the Zulu sheep breed with rams having higher values in most morphometric traits than ewes. Damara ewes had significantly ($p<0.05$) higher mean values for head length, ear length, neck length and tail length than rams. However, there were no significant ($p>0.05$) sex differences in body length, shoulder width, ear width and cannon bone length in the Damara breed.

The Tswana breed had similar ($p>0.05$) body weight and most linear body measurements between all the sexes except for rump height, tail length and tail circumference. These findings are consistent with earlier findings in indigenous sheep breeds of Ethiopia (Abera *et al.,* 2014; Michael *et al.,* 2016) wherein no significant differences between rams and ewes in body weight and most linear body measurements of. This indicates the absence of sexual dimorphism for body weight and most morphometric traits in the Tswana sheep breed. The Tswana sheep used in the current study is a closed conservation flock that does not interbreed with other sheep and is kept in very small numbers, therefore chances of inbreeding may be very high and which may result in less variation across the whole flock. Also, the population consist of more female animals than males as only those males selected for breeding purposes are kept, while the rest of the male population is castrated or culled. As such, the small number of males may not be a good representation of the whole male population, hence lack of sexual dimorphism in most morphometric traits in the Tswana sheep breed.Contrary to the current findings, Mavule (2012) and Bolowe *et al.* (2021) reported a significant sex difference in body weight and most linear body measurements for Zulu and Tswana sheep breeds, respectively. A significant trend was found in these studies, where rams tended to have higher body weight and most linear body measurements than ewes.

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 & Hafezian, 2009).

Table 3.2. 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±1.98b	51.7±1.72b	80.5±8.06a	68.9±1.52a	59.0±1.12b	58.9±2.85b	70.2±4.65a	52.4±1.02b	51.3±6.58b	73.8±1.60a	57.5±1.15b	71.0±4.31a	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±0.81a	71.8±0.59b	80.3±2.20a	61.3±2.91	56.5±1.01	55.5±1.75
HG (cm)	87.2±1.28b	83.6±1.11c	102.5±5.22a	96.4±0.99a	87.3±0.72b	88.1±1.84b	97.8±3.01a	88.6±0.66b	82.3±4.26b	95.9±1.03a	87.4±0.75b	93.4±2.79a	82.0±3.69	74.9±1.28	75.9±2.22
HW (cm)	74.3±0.75a	71.5±0.65b	79.5±3.07a	68.1±0.58a	64.2±0.42b	66.6±1.08a	75.3±1.77a	66.4±0.39b	69.3±2.50b	75.0±0.61a	69.8±0.44b	75.0±1.64a	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±0.85b	29.2±1.39a	25.7±0.30b	25.0±1.96b	31.6±0.48a	23.6±0.34c	28.1±1.29b	18.8±1.70	17.3±0.59	18.8±1.03
RH (cm)	74.1±0.68b	73.1±0.59b	81.5±2.76a	66.8±0.52a	63.3±0.38b	65.3±0.98ab	74.2±1.59a	65.7±0.35b	69.0±2.25ab	73.2±0.55a	70.1±0.39b	73.6±1.48a	66.4±1.95a	62.0±0.68b	63.5±1.18ab
RW (cm)	20.5±0.41a	18.6±0.36b	23.5±1.67a	25.3±0.32a	24.0±0.23b	24.1±0.59ab	25.7±0.97a	23.1±0.21b	21.7±1.36b	23.9±0.33a	22.7±0.24b	24.9±0.89a	18.5±1.18	17.0±0.41	17.2±0.71
HL (cm)	18.1±0.40b	19.5±0.34a	20.0±1.61a	20.6±0.30a	18.8±0.22b	19.2±0.57b	17.8±0.93	18.2±0.20	19.0±1.32	23.5±0.32a	19.2±0.23b	20.6±0.86b	18.1±1.14	16.2±0.40	15.9±0.69
HDW (cm)	12.5±0.21a	10.5±0.18b	12.5±0.86a	13.9±0.16a	11.3±0.11b	11.7±0.30b	14.8±0.50a	12.1±0.11b	11.3±0.70b	13.9±0.17a	11.7±0.12c	12.9±0.46b	9.6±0.61	8.7±0.21	8.6±0.37
HNL (cm)	29.8±1.71a	7.9±1.79b	12.3±6.93b	NONE	NONE	NONE	52.7±5.66a	11.0±6.93b	14.8±6.93b	NONE	NONE	NONE	NONE	NONE	NONE
NL (cm)	25.7±0.97b	28.3±0.84a	24.0±3.94ab	30.9±0.74a	28.5±0.54b	28.1±1.39ab	27.2±2.27	27.7±0.50	28.0±3.22	39.5±0.78a	26.3±0.56c	31.6±2.11b	20.3±2.79	19.6±0.97	19.1±1.68
EL (cm)	11.6±0.27b	13.3±0.24a	13.5±1.11a	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±0.22a	12.7±0.16b	13.1±0.59b	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±0.09a	6.3±0.07b	6.3±0.17b	7.5±0.28b	7.6±0.06a	6.3±0.39c	7.2±0.10a	6.9±0.07b	7.0±0.26ab	5.9±0.34	6.0±0.12	6.0±0.20
TL (cm)	55.1±1.30b	51.0±1.13a	56.0±5.29ab	NONE	NONE	NONE	NONE	NONE	NONE	44.5±1.05a	40.3±0.76b	43.4±2.83ab	42.0±7.48a	28.0±7.48ab	19.0±7.48b
TC (cm)	20.4±0.71b	17.0±0.62c	26.9±2.90a	NONE	NONE	NONE	NONE	NONE	NONE	19.5±0.57a	12.9±0.41b	20.0±1.55a	23.5±4.10ab	12.5±4.10b	31.5±4.10a
CBC (cm)	7.8±1.18a	6.7±0.15b	8.5±0.73a	9.2±0.14a	7.9±0.10b	8.2±0.26b	9.2±0.42a	7.4±0.09b	6.7±0.59b	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±0.24a	13.3±0.17b	13.6±0.44b	15.5±0.72a	14.0±0.16b	13.3±1.02b	17.9±0.25a	15.1±0.18b	16.6±0.67a	12.3±0.89	11.0±0.31	11.6±0.53
SC (cm)	24.1±0.66	NONE	NONE	27.5±0.51	NONE	NONE	25.8±1.55	NONE	NONE	25.6±0.53	NONE	NONE	21.5±1.90	NONE	NONE

[a,b,c] Raw means with different superscripts within a breed are significantly different ($p<0.05$), 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.

3.4.3 Effects of breed on body weight and linear body measurements of rams

Body weight and morphometric traits vary ($p<0.05$) in rams across different sheep breeds (Table 3.3) and this is consistent with Agbaye *et al.* (2021) who found a similar trend in Balami, Ouda, Yankasa and West African Dwarf rams in Nigeria. There were significant differences ($p<0.05$) in body weight and most linear body measurements across the breeds except for tail circumference. Meat-master, Dorper and Karakul rams had significantly ($p<0.05$) higher body length, head width, heart girth and ear width than their indigenous (Tswana and Damara) counterparts. This could be 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. Damara rams however had significantly ($p<0.05$) higher body length, shoulder width and head width than Tswana rams, but the two breeds had similar body weight, heart girth, ear width and rump width. The similarity of these breeds in some traits may be because both Damara and Tswana are indigenous breeds that have been naturally selected to better adapt to harsh environmental conditions in their places of origin, while the differences in other traits may be due to artificial selection and the effects of evolutionary forces or just adaptation to their environments.. The Damara and Tswana breeds do not gain much muscle and they are naturally smaller in size compared to their exotic counterparts, which is a survival trait as smaller animals generally require less feed (Becker, 2021) and can better escape predators than the heavier meat breeds. A similar trend where indigenous breeds recorded lower values in body weight and most morphometric traits was observed by Mavule (2012), Mohammed *et al.* (2018) and Bolowe *et al.* (2021).

Meat-master rams had significantly ($p<0.05$) higher body weight, neck length, and shoulder width than Dorper, Damara and Tswana rams.This is consistent with Becker (2021) who reported a higher body weight (73.8 kg) in Meat-master rams than Dorper rams (54.15 kg). 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 parents (Becker, 2021). Dorper rams in the study were, however, heavier ($p<0.05$) than their indigenous counterparts. Higher body weight and shoulder width in Dorper rams than Damara and Tswana rams are consistent with Mohammed *et al.* (2018), who reported higher body weight and most morphometric traits in pure-bred Dorper than in Dorper crosses and local Ethiopian sheep breeds. There were no significant ($p>0.05$) differences in body weight and shoulder width between Meat-master and Karakul rams.

This might be because for Karakul rams, only breeding rams that were 3 years and above participated in the study as young males are usually sacrificed immediately after birth for pelt production, hence the sample was not as representative as that of other breeds in the study. The body weight of Karakul rams in the current study was much higher than that reported by Musavi *et al.* (2022) (47.6 kg) for Karakul rams in North Afghanistan.

Significantly lower ($p<0.05$) cannon bone circumference was found in Damara, Meat-master and Tswana rams than in Dorper and Karakul rams. Cannon bone circumference for Damara, Meat-master and Tswana (7.8 cm, 7.7 cm and 7.6 cm, respectively) was consistent with that reported by Bolowe *et al.* (2021) (7.46 cm) for Tswana rams. The significantly lower cannon bone circumference of the Damara and Tswana rams could be an adaptive feature that allows these indigenous breeds to walk long distances in search of pasture and water, and to be able to flee from predators. Becker (2021) argued that Meat-master acquired adaptive traits from the parent breed Damara, which might have contributed to Meat-master having similar cannon bone circumference with Damara and Tswana. Significantly higher ($p<0.05$) cannon bone circumference in Dorper and Karakul rams than the other breeds observed may be attributed to the fact that a strong thick cannon bone is needed to support the weight of an animal, such is one of the characteristics of a good meat animal (Cloete *et al.*, 2000). Meat-master rams had the highest ($p<0.05$) cannon bone length than other breeds and there were no significant ($p>0.05$) differences in cannon bone length of Damara, Dorper and Karakul rams.

The Dorper rams had significantly ($p<0.05$) larger scrotal circumference (27.5 cm), followed by Karakul (25.8 cm), Meat-master (25.6 cm), Damara (24.1 cm) and lastly Tswana (21.5 cm). Cloete *et al.* (2000) reported that Dorper rams reach sexual maturity early, which might have contributed to them having higher scrotal values as compared to other breeds. This trait indicates that the Dorper rams have a good reproductive potential as compared to male counterparts of the other breeds which are favorable when selecting breeding rams. Furthermore, the scrotal size has a positive correlation with sperm production (van Wyk, 2010) and a desirable negative correlation with age at puberty of the progeny. The scrotal circumference of Dorper rams in this study is similar to that reported by Michael *et al.* (2016) (27.5 cm) for East Gojam indigenous sheep types in Ethiopia. On contrary, greater scrotal circumference (32.55 cm) in the same breed had been reported in South Africa (Becker, 2021).

Table 3.3. 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}	NONE	52.7 ± 5.66^{a}	NONE	NONE
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}	NONE	NONE	44.5 ± 1.05^{b}	42.0 ± 7.48^{b}
TC (cm)	20.4 ± 0.71	NONE	NONE	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 ($p<0.05$), 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.

3.4.4 Effects of breed on body weight and linear body measurements of ewes

There were significant ($p<0.05$) differences in body weight and all linear body measurements in ewes across different sheep breeds except for horn length (Table 3.4). Consistent with the current findings, Mohammed *et al.* (2018) reported significant differences in body weight and most linear body measurements between pure-bred Dorper, Dorper crosses and indigenous Ethiopian sheep breed. Dorper and Meat-master ewes were significantly heavier ($p<0.05$), followed by Karakul and Damara, and lastly Tswana sheep. Dorper ewes had significantly ($p<0.05$) higher values in body length, shoulder width and rump width than their age-matched counterparts. However, there were no differences ($p>0.05$) in heart girth between Dorper, Karakul and Meat-master ewes. Contrary to this, Becker (2021) reported body weight and morphometric traits which were higher for Meat-master ewes than their Dorper counterparts. 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 different environmental (management) effects, and intensities of evolutionary forces such as mutations and selection which force animals to evolve in a certain way to better survive and reproduce in each environment.

The body weights of Damara and Karakul ewes were similar ($p>0.05$) but significantly higher ($p<0.05$) than those of Tswana ewes. Tswana and Karakul ewes in this study were much heavier than those reported by Bolowe *et al.* (2021) in Botswana and Musavi *et al.* (2022) in North Afghanistan, respectively. The differences in body weight could be that sheep in the current study are kept under semi-intensive management systems where there is constant supplementation, whereas those in the study by Bolowe *et al.* (2021) were kept in communal areas where there is 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. However, all the breeds in this study are lighter as compared to the Ouled-Djellal breed in Algeria (Harkat *et al.*, 2015).

Damara ewes had significantly ($p<0.05$) higher values of height at withers, rump height, head width, head length, ear length, neck length, tail length, tail circumference, and cannon bone length than other breeds in the study. Tswana and Damara ewes had similar ($p>0.05$) and significantly lower ($p<0.05$) cannon bone circumference than their exotic counterparts. This could be an adaptive trait of the indigenous breed, which may help the animal to walk long distances and survive periods of nutrition scarcity. 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. The significantly ($p<0.05$) higher values for tail length and tail circumference in Damara and Tswana ewes are also survival traits 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.

Table 3.4. 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	NONE	11.0±6.93	NONE	NONE
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}	NONE	NONE	40.3±0.76^{b}	28.0±7.48^{b}
TC (cm)	17.0±0.62^{a}	NONE	NONE	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 ($p<0.05$), 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.

3.4.5 Effects of breed on body weight and linear body measurements of castrates

There were significant ($p<0.05$) differences in body weight and linear body measurements of castrates of five different sheep breeds (Table 3.5). There were however no significant ($p>0.05$) breed differences in horn length and ear length among castrates in the study. Body weight, heart girth, cannon bone length and height at withers were significantly ($p<0.05$) higher in Damara and Meat-master castrates than in other breeds. The high body weight, heart girth, cannon bone length and height at withers in Damara castrates may 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 (Yoseph, 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 ($p<0.05$) than their age-matched Dorper counterparts indicating their capability to produce more meat than the Dorper. Becker (2021) highlighted that the Meat-master breed has inherited the ability to produce heavier carcasses from one of its parent breeds, the Dorper and thus has also benefited from hybrid vigor thereby performing better than the Dorper.

Meat-master castrates had significantly ($p<0.05$) higher body length, head width and ear width than castrates of the other four breeds. The Dorper, Karakul and Damara castrates had similar ($p>0.05$) body length, head width and ear width, which were significantly higher than those of the Tswana castrates. This could be because the Tswana is generally a medium-sized breed (Nsoso *et al.*, 2004; Bolowe *et al.*, 2021) that has been naturally selected to adapt to harsh Botswana conditions as medium size helps it to easily regulate body temperature during hot days compared to exotic breeds. There were no significant ($p>0.05$) differences in shoulder width, rump width and head length among the breeds except for the Tswana castrates. Tswana castrates in this study had lower body length, head width, rump width, head length and ear width than those reported by Bolowe *et al.* (2021).

The tail length of the Damara was the longest (56.0 cm), followed by Meat-master (43.4 cm) and lastly Tswana (19.0 cm). However, the tail circumferences of Tswana and Damara castrates were similar ($p>0.05$). The Damara breed is characterized by a long fat tail (Almeida, 2011), while Tswana fall under short fat-tailed breeds (Bolowe *et al.*, 2021). The fat tail acts as an adaptive trait in indigenous breeds as it stores fat which later helps the animal survive in poor nutritional environments. Meat-master castrates have long moderate fat tails, which is an adaptive trait inherited from the Damara as a parent breed (Becker, 2021). Cannon bones of Meat-master castrates in this study were thicker ($p<0.05$) than those of other exotic breeds to enable the breed to better support its body weight.

Table 3.5. 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	NONE	14.8±6.93	NONE	NONE
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}	NONE	NONE	43.4±2.83^{b}	19.0±7.48^{c}
TC (cm)	26.9±2.90^{a}	NONE	NONE	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 ($p<0.05$), 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.

3.5 Conclusions

Tswana sheep are characterized by patchy coat color patterns with white being the dominant coat color and the 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 dominant coat colors, respectively. Breed and sex have a significant influence on body weight and linear body measurements across all five sheep breeds. Tswana sheep had the lowest body weight and most morphometric traits in all the sexes as compared to other sheep breeds. Meat-master, Dorper and Karakul sheep breeds had higher body weights and most 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 favoring males than females.

3.6 References

Abera, B., Kebede, K., Gizaw, S., & Feyera, T. (2014). On-Farm Phenotypic Characterization of Indigenous Sheep Types in Selale Area, Central Ethiopia. *Veterinary Science and Technology, 5* (3), 1-6.

Aganga, A.O. and A.A. Aganga (2015) Quality assurance in goat meat production for food safety in Botswana. *Asian Journal of Biological Sciences, 8* (2), 51-56.

Agbaye, F.P., Sokunbi, A.O., Onigemo, M.A., Alaba, O., Anjola, O.A.J., Amao, E.A., Oso, Y.A.A., Agbalaya, K.K., Ishola, O.J., & Yusuf, B. (2021). Variation in body measurements and semen quality of Nigeria sheep breeds. *Nigerian Journal of Animal Production, 48* (1), 55-61.

Almeida, A.M. (2011). The Damara in the context of Southern Africa fat-tailed sheep breeds. *Tropical Animal Health Production,* 43, 1427-1441.

Baleseng, L., Kgosikoma, O.E., & Makgekgenene, A. (2016). Performance of goats and sheep under communal grazing in Botswana using various growth measures. *Rome,* 1-7.

Baneh, H., & Hafezian, S. H. (2009). Effect of environmental factor on growth traits in Ghezel sheep. *African Journal of Biotechnology,* 8, 2903-2907.

Becker, S.J. (2021). Phenotypic characterisation of Meatmaster sheep using quantitative and qualitative trait analysis. *Masters thesis.* Central University of Technology. Free State, South Africa.

Bolowe, M.A., Thutwa, K., Kgwatalala, P.M., Monau, P.I., & Malejane, C. (2021). Phenotypic characterization of indigenous Tswana sheep population in selected Districts of Southern Botswana. *African Journal of Agricultural Research, 17* (10), 1268-1280.

Cloete, S.W.P., Snyman, M.A., & Herselman, M.J. (2000). Productive performance of Dorper sheep. *Small Ruminant Research,* 36, 119-135.

FAO. (2012). Phenotypic characterization of Animal Genetic Resources. url: www.fao.org/docrep/015/ i2686e/i2686e00.pdf.

Fourie, P.J., Neser, F.W.C., Olivier, J.J., & Van der Westhuizen, C. (2002). Relationship between production performance, visual appraisal and body measurements of young Dorper rams. *South African Journal of Animal Sciences, 32* (4).

Hailemariam, F., Gebremicheal, D., & Hadgu, H. (2018). Phenotypic characterization of sheep breeds in Gamogofa zone. *Agriculture and Food Security, 7* (27), 1-7.

Hailu, A., Mustefa, A., Aseged, T., Assefa, A., Sinkie, S., Tsewene, S. (2020). Phenotypic characterization of sheep populations in Tahtay Maichew district, Northern Ethiopia. *Genetic Resources, 1* (2), 12-22.

Harkat, S., Laoun, A., Benali, R., Outayeb, D., Ferrouk, M., Maftah, A., Da Silva, A., &Lafri, M. (2015). Phenotypic characterization of major sheep breed in Algeria. *Revenue Medical Veterinary, 166* (6), 138-147.

Janssens, S., & Vandepitte, W. (2004). Genetic parameters for linear measurements and linear type traits in Belgian Bleu du Maine, Suffolk and Texel sheep. *Small Ruminants Research,* 54, 13-24.

Kandiwa, E., Mushonga, B., Madzingira, O., Samkange, A., Bishi, A., & Tuaandi, D. (2019). Characterizaion of Oestrus Cycles in Namibian Swakara and Damara Sheep through Determination of Circannual Plasma Progesterone Levels. *Journal of Veterinary Medicine,* 18, 1-6.

Kgaudi, K. (2014). Milk production potential and major browse species consumed by dromedary camels (Camelus dromedarius) in Tsabong area, Southern Kgalagadi District. BSc Dissertation, Botswana College of Agriculture, Gaborone, Botswana.

Mavule, B.S. (2012). Phenotypic characterization of Zulu sheep: Implications for conservation and improvement. *Masters Dissertation*. University of Zululand, South Africa.

Michael, A., Kefelegn, K., & Yoseph, M. (2016). Phenotypic Characterization of Indigenous Sheep Types in Northern Ethiopia. *Journal of Natural Sciences Research, 6* (15), 16-27.

Mohammed, J., Abegaz, S., Lakew, M., & Tarekegn, G.M. (2018). Phenotypic Characterization of Dorper, Local Sheep and Their Crossbred Sheep Population in North Eastern Amhara, Ethiopia. *Journal of Biology, Agriculture and Healthcare, 8* (1), 15-25.

Musavi, S. A. A., Khadimiyan, A. M., & Azimi, A. M. (2022). Morphological Characterization of Karakul Sheep in North Part of Afghanistan. *Voice of the Publisher,* 8, 16-25.

Ngcobo, J.N., Nedambale, T.L., Nephawe, K.A., Mpofu, T.J., Chokoe, T.C., Ramukhithi, F.V. (2022). An Update on South African Indigenous Sheep Breeds' Extinction Status and Difficulties during Conservation Attempts: A Review. *Diversity,* 14, 516.

Nsoso, S.J., Podisi, B., Otsogile, E., Mokhutshwane, B.S., & Ahmadu, B. (2004). Phenotypic Characterization of Indigenous Tswana Goat and Sheep Breeds in Botswana: Continuous Traits. *Tropical Animal Health and Production,* 36, 789-800.

Seifu, E., Madibela, O.R., & Teketay, D. (2019). Camels in Botswana: Herd dynamics and future development implications. *Botswana Journal of Agriculture and Applied Sciences, 13* (1), 12-25.

Selala, L.J., & Tyasi, T.L. (2022). Using Morphological Traits to Predict Body Weight of Dorper Sheep Lambs. *World Veterinary Journal, 12* (1), 66-73.

Statistics Botswana. (2016). *Agricultural census brief report of 2016-2022*. Retrieved from https://www.statsbots.org.bw/agriculture.

Van Wyk, J.B. (2010). Applied animal breeding (DTL 424- Module guide). University of the Free State. Bloemfontein, South Africa.

Von Wielligh, W. (2001). The Damara Sheep as Adapted Sheep Breed in Southern Africa, Community-based Management of Animal Genetic Resources Congress. *Food and Agriculture Organization of the United Nations.* Mbabane, Swaziland, 173–175.

Wilson, R.T., & Durkin, J.W. (1984). Age at permanent incisor eruption in indigenous goats and sheep in semi-arid Africa. *Livestock Production Science, 11* (4), 451-455.

Yoseph, M. (2007). Reproductive traits in Ethiopian male goats: With special reference to breed and nutrition. *Doctoral thesis*. Swedish University of Agricultural Sciences. Uppsala, Sweden.

CHAPTER 4

Phenotypic correlations between live body weight and linear body measurements and Regression Equations for prediction of live weight in different sheep breeds of Botswana

4.1 Abstract

The study was conducted to determine the relationships between body weight and morphological traits, and develop regression equations using morphometric traits for different sheep breeds under ranch management system. Correlation coefficients were determined from a total of 595 sheep (Damara: 79, Dorper: 177, Karakul: 135, Meat-master: 156 and Tswana: 48), while regression equations were estimated from a total of 94 sheep (Damara: 20, Dorper: 30, Karakul: 16, and Meat-master: 28) using Statistical Analysis System (SAS) 9.4. The highest positive, and significant ($p<0.05$) correlation coefficients were found between body weight and heart girth in both sexes across different sheep breeds, with males having higher correlation coefficients than females, except for Karakul males. Body length had significantly ($p<0.05$) higher correlation coefficient ($r = 0.81$, 0.79, and 0.97) with body weight compared to height at withers ($r = 0.78$, 0.44, and 0.08) in males of Dorper, Meat-master, and Tswana sheep breeds, respectively. Linear body measurements like heart girth, body length, height at withers, neck length, cannon bone length, cannon bone circumference and scrotal circumference in males were used to estimate the body weight of Dorper, Damara, Meat-master and Karakul sheep breeds. Heart girth accounted for more variability in the prediction model for all the breeds, both males and females, except for Damara males. Heart girth and body length explained more variability in the model used to predict the body weight of Damara males, which means these traits can be used as selection criteria for body weight. The addition of more independent variables increases the accuracy of the prediction equation.

Keywords: Morphometric traits, prediction equations, relationships

4.2 Introduction

Body weight plays a critical role in influencing farmers' decision-making regarding animal management practices (Rotimi *et al.*, 2020). This is because body weight determines the amount of feed consumed by the animal (maintenance cost) and the dosage rate when administering medical drugs (Kunene, 2010). Also, the condition of the animal can be easily assessed using body weight especially during marketing and determination of livestock sale prices in rural areas (Temoso *et al.*, 2017). According to Becker (2021), even though body weight is a main indicator of growth in sheep, it does not describe the morphological composition of the animal. As such, morphological traits such as heart girth, body length and height at withers can also be used as growth indicators. Heart girth has been found to have the highest correlation coefficient with body weight in both goats and sheep (Temoso *et al.*, 2017; Bolowe *et al.*, 2021). This indicates that heart girth can be used as an indirect selection criterion for body weight in sheep. Even though body weight is a major trait of economic importance, farmers in rural areas do not directly select for body weight in order to maximize response to selection due to the lack of weighing scales. Consequently, this resulted in farmers using visual observations to determine the body weight of animals, which may be prone to individual errors and inaccuracies (Kunene, 2010; Sebolai *et al.*, 2012). The use of linear body measurements and prediction equations sis much more practical and easier to use under field conditions in the absence of weighing scales to predict animal body weight (Mahmud *et al.*, 2014). The farmer only has to know the prediction equation, then take a few measurements using a measuring tape or ruler, and lastly fit the measurements in the equation to come up with the animal body weight. Studies have been done on phenotypic correlations and the use of linear body measurements to predict the body weight of Tswana, Meat-master and Dorper sheep breeds in Botswana and South Africa (Bolowe *et al.*, 2021; Becker, 2021; Selala &Tyasi, 2022), but not all sheep breeds found in Botswana were covered. Also, the study by Bolowe *et al* . (2021) on Tswana sheep only focused on extensively managed sheep populations in the Southern District of Botswana, while studies on other breeds like the Dorper and Meat-master were carried out outside Botswana. This makes it essential to carry out the same studies in our local Botswana environmental conditions. From the review of the literature, studies on correlation coefficients between body weight and linear body measurements and regression equations using linear body measurements to predict body weight have not been carried out in Karakul and Damara sheep breeds. The objectives of this study were therefore to estimate phenotypic correlations between body weight and various linear body measurements and develop prediction regression equations using linear body measurements for Tswana, Dorper, Karakul, Meat-master and Damara sheep breeds under ranch management conditions in Botswana.

4.3 Materials and Methods

4.3.1 Study site

The study was carried out from March 2023 to August 2023 at Lobu field station, which is located south-west of Botswana in the Kgalagadi South district (26°35'13'S 21°49'02'E). The Kgalagadi area is characterized by low summer rainfalls with an average rainfall of 300mm per annum, which contributes to extreme temperatures ranging from 29 to 35 degrees Celsius during summer and from 1 to 12 degrees Celsius during winter (Seifu *et al.*, 2019). The research area is an arid savannah woodland and grassland, with sparsely distributed vegetation and various grass species (Kgaudi, 2014).

4.3.2 Study animals

A total of five hundred and ninety-five (595) sheep (Damara: 79, Dorper: 177, Karakul: 135, Meat-master: 156 and Tswana: 48) were used for linear body measurements and to estimate phenotypic correlations between body weight and linear body measurements for five sheep breeds. The sample size was determined by the sheep populations at the study site. Ninety-four (94) sheep (Damara: 20, Dorper: 30, Karakul: 16, and Meat-master: 28) were used to develop regression equations used to predict the body weight of the four sheep breeds. Only adult sheep (non-pregnant) aged two and three years participated in the construction of the regression equations, while those animals which were 1 year and above 3 years old were excluded from this study (2 years old ≤ animal ≤ 3 years old). The age of the sheep was estimated using the dentition procedure described by Wilson & Durkin (1984).

4.3.3 Data collection

Quantitative traits were measured using a flexible measuring tape, following the breed morphological characteristics descriptor list for phenotypic characterization of sheep by FAO (2012). Quantitative traits which were measured included body length (BL), heart girth (HG), height at withers (HW), shoulder width (SW), rump height (RH), rump width (RW), neck length (NL), tail length (TL), tail circumference (TC), cannon bone circumference (CBC), cannon bone length (CBL) and scrotal circumference (SC) for rams. A weighing band was used to estimate the body weight (BW) of the sampled sheep populations used for the estimation of phenotypic correlations. Morphometric traits that were measured for the development of regression equations included body length (BL), height at withers (HW), heart girth (HG), cannon bone length (CBL), cannon bone circumference (CBC) and scrotal circumference (SC) in males. A weighing scale was used to measure the actual body weight (BW) of sheep used for the construction of regression prediction equations of both males and females of Damara, Dorper, Karakul and Meat master sheep breeds of Botswana.

4.3.4 Statistical analysis

Correlation coefficients of Tswana, Dorper, Damara, Meat-master and Karakul sheep breeds were estimated between body weight and other linear body measurements (LBMs) within each sex using the procedure correlation (PROC CORR) of Statistical Analysis System (SAS, release 9.4 2013). Linear body measurements which were correlated to body weight were then subjected to regression analysis to develop prediction equations for body weight. Stepwise multiple regression procedures (PROC REG) of SAS 9.4 were used for regression analysis. Independent variables were first individually regressed, and then step-wise addition of more independent variables was done to determine the best predictor variables to estimate body weight in each sex. The regression models were selected on the basis of the coefficient of determination (R^2) and the adjusted R^2. The regression models with the highest coefficient of determination (closer to 1.00 (100%)) were selected, as they accounted for more variability in body weight than others. The complete regression model for the linear body measurements was defined as follows;

For female:

$$Yj = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + ej$$

Where:

Yj = dependent variable (body weight)

β_0 = the intercept

X_1, X_2, X_3, X_4, X_5, and X_6 = independent variables BL, HG, HW, CBC, CBL, and NL, respectively.

β_1, $\beta_2 \ldots \beta_6$ = regression coefficients of the variables X_1, $X_2 \ldots X_6$.

ej = random error

For males:

$$Yj = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + ej$$

Where:

Yj = dependent variable (body weight)

β_0 = the intercept

X_1, X_2, X_3, X_4, X_5, X_6, and X_7 = independent variables BL, HG, HW, CBC, CBL, NL and SC, respectively.

β_1, $\beta_2 \ldots \beta_7$ = regression coefficients of the variables X_1, $X_2 \ldots X_7$.

ej = random error

4.4 Results and Discussion

4.4.1 Phenotypic correlations between body weight and linear body measurements in males

Strong, positive, and significant ($p<0.05$) correlations were observed between body weight and most linear body measurements like body length (r = 0.74, 0.81, 0.79, and 0.97), heart girth (r = 0.94, 0.95, 0.90, and 0.97) and shoulder width (r = 0.86, 0.95, 0.65, and 0.99) for males of Damara, Dorper, Meat-master, and Tswana sheep breeds, respectively (Table 4.1). The results are consistent with the findings of Becker (2021), Bolowe *et al.* (2021) and Selala & Tyasi (2022) who reported strong, significantly positive associations between body weight and morphometric traits like body length and heart girth for Meat-master, Tswana and Dorper male sheep, respectively. This indicates that body weight in rams can be indirectly selected through the selection of these quantitative traits (heart girth, body length, and shoulder width) as they simultaneously increase with the increase in body weight. The correlation coefficients between body weight and all other measured morphometric traits for Karakul males were non-significant (p0.05), with positive and moderate associations only occurring between body weight and body length (r = 0.63), heart girth (r = 0.65) and rump width (r = 0.55). Non-significant ($p>0.05$), weak correlation coefficients were observed between body weight and neck length (r = 0.22, and 0.17) for Damara and Karakul males, respectively. Weak and non-significant ($p>0.05$) associations were also found between body weight and cannon bone length (r = 0.02, -0.16, and 0.07) in Damara, Karakul and Meat-master males, respectively. Significant (p<0.05) positively strong correlation coefficients were found between body weight and neck length and between body weight and cannon bone length in Dorper and Tswana males, respectively. Bolowe *et al.* (2021) however found positive moderate correlations between body weight and neck length and cannon bone length in Tswana sheep males. Karakul and Meat-master males had a weak correlation coefficient between body weight and tail length, and this is consistent with Becker (2021) who reported weak correlations between body weight and tail length of Meat-master rams. Significant (p<0.05), strong, and positive correlations were observed between body weight and tail circumference (r = 0.84, and 0.74), and significant (p<0.05) moderate correlations occurred between body weight and scrotal circumference (r = 0.62, and 0.74) in Damara and Meat-master males, respectively. This indicates that selecting heavier Damara and Meat-master males will result also in big tails and higher scrotal circumference. Becker (2021) however reported weak positive, correlations between body weight and scrotal circumference (r = 0.47) in Meat-master rams in South Africa. Height at withers (r = -0.30), shoulder width (r = -0.01), rump height (r = -0.50), tail length (r = -0.34), cannon bone circumference (r = -0.01), and cannon bone length (r = -0.16) of Karakul males had no significant (p>0.05), negative correlations with body weight. This suggests that directly selecting for body weight in Karakul males will indirectly reduce height at withers, shoulder width, rump height, tail length, and cannon bone circumference of Karakul Sheep.

Table 4.1. Phenotypic correlations between body weight and other morphometric traits in males of different sheep breeds

Breed	Trait	BW	BL	HG	HW	SW	RH	RW	NL	TL	TC	CBC	CBL	SC
Damara	BW	1	0.744*	0.937*	0.748*	0.859*	0.837*	0.730*	0.223	0.638*	0.835*	0.659*	0.021	0.624*
Dorper		1	0.809*	0.946*	0.781*	0.953*	0.755*	0.785*	0.842*	0.0	0.0	0.449*	0.674*	0.348*
Karakul		1	0.634	0.649	-0.298	-0.008	-0.499	0.547	0.174	-0.337	0.03	-0.014	-0.162	0.174
Meat-master		1	0.792*	0.904*	0.444*	0.650*	0.593*	0.635*	0.455*	0.389*	0.743*	0.726*	0.067	0.736*
Tswana		1	0.966*	0.972*	0.078	0.990*	0.937	0.931	0.952*	0.0	0.0	-0.702	0.979*	0.69
Damara	BL		1	0.657*	0.811*	0.732*	0.712*	0.646*	0.197	0.615*	0.674*	0.594*	-0.101	0.485*
Dorper			1	0.764*	0.647*	0.808*	0.652*	0.687*	0.730*	0.0	0.0	0.335*	0.573*	0.26
Karakul			1	0.716	-0.122	0.025	-0.497	0.842*	0.736	0.183	0.562	-0.438	0.155	-0.235
Meat-master			1	0.798*	0.436*	0.556*	0.635*	0.639*	0.453*	0.335*	0.639*	0.677*	-0.008	0.632*
Tswana			1	0.886	0.319	0.991*	0.982*	0.819	0.984*	0.0	0.0	-0.856	0.912	0.822
Damara	HG			1	0.626*	0.872*	0.760*	0.772*	0.091	0.558*	0.758*	0.691*	0.188	0.680*
Dorper				1	0.793*	0.842*	0.828*	0.850*	0.649*	0.0	0.0	0.615*	0.694*	0.520*
Karakul				1	-0.068	-0.376	-0.551	0.418	0.462	0.057	0.27	-0.458	-0.497	0.204
Meat-master				1	0.497*	0.681*	0.578*	0.665*	0.340*	0.400*	0.643*	0.720*	-0.008	0.707*
Tswana				1	-0.155	0.939	0.827	0.991*	0.853	0.0	0.0	-0.52	0.960*	0.499

Damara	HW	1	0.714*	0.841*	0.427*	0.478*	0.646*	0.748*	0.456*	-0.176	0.464*
Dorper		1	0.693*	0.922*	0.695*	0.600*	0.0	0.0	0.449*	0.553*	0.296*
Karakul		1	-0.686	0.8	-0.572	0.544	-0.069	-0.485	-0.181	0	-0.683
Meat-master		1	0.535*	0.795*	-0.091	0.174	0.239	0.046	0.184	0.278*	0.135
Tswana		1	0.193	0.413	-0.283	0.365	0.0	0.0	-0.763	0	0.748
Damara	SW		1	0.787*	0.684*	0.235	0.642*	0.710*	0.648*	0.212	0.632*
Dorper			1	0.664*	0.734*	0.886*	0.0	0.0	0.307*	0.633*	0.259
Karakul			1	-0.513	0.45	-0.315	-0.241	0.622	-0.108	0.243	0.018
Meat-master			1	0.5268	0.432*	0.292*	0.488*	0.552*	0.459*	0.340*	0.454*
Tswana			1	0.960*	0.887	0.969*	0.0	0.0	-0.782	0.945	0.748
Damara	RH			1	0.454*	0.440*	0.563*	0.740*	0.479*	-0.008	0.574*
Dorper				1	0.795*	0.468*	0.0	0.0	0.521*	0.615*	0.474*
Karakul				1	-0.676	0.101	0.075	-0.727	0.374	0.344	-0.474
Meat-master				1	0.024	0.235	0.194	0.206	0.322*	0.061	0.266
Tswana				1	0.744	0.999*	0.0	0.0	-0.895	0.906	0.899
Damara	RW				1	-0.392	0.326	0.458*	0.856*	0.212	0.568*
Dorper					1	0.435*	0.0	0.0	0.648*	0.640*	0.542*
Karakul					1	0.345	0.272	0.701	-0.166	0.371	0.027
Meat-master					1	0.211	0.371*	0.785*	0.624*	0.03	0.641*
Tswana					1	0.775	0.0	0.0	-0.405	0.923	0.378
Damara	NL					1	0.528*	0.458*	-0.311	-0.275	0.068
Dorper						1	0.0	0.0	0.093	0.497*	-0.044
Karakul						1	0.165	0.295	-0.581	0.186	-0.724
Meat-master						1	0.266	0.346	0.331*	-0.123	0.318*
Tswana						1	0.0	0.0	-0.87	0.927	0.878
Damara	TL						1	0.666*	0.25	-0.189	0.292
Dorper							0.0	0.0	0.0	0.0	0.0
Karakul							1	0.163	0.257	0.471	0.189
Meat-master							1	0.547*	0.197	0.211	0.123
Tswana							0.0	0.0	0.0	0.0	0.0
Damara	TC							1	0.355*	-0.267	0.485*
Dorper								0.0	0.0	0.0	0.0
Karakul								1	-0.646	0.036	-0.085
Meat-master								1	0.583*	0.054	0.703*
Tswana								0.0	0.0	0.0	0.0
Damara	CBC								1	0.452*	0.692*
Dorper									1	0.299*	0.692*
Karakul									1	0.447	0.427
Meat-master									1	0.056	0.777*
Tswana									1	-0.623	-0.968
Damara	CBL									1	0.524*
Dorper										1	0.113
Karakul										1	-0.368
Meat-master										1	-0.064
Tswana										1	0.659
Damara	SC										1
Dorper											1
Karakul											1
Meat-master											1
Tswana											1

*=p≤0.05, BW=body weight, BL=body length, HG=heart girth, HW=height at withers, SW=shoulder width, RH=rump height, RW=rump width, NL=neck length, TL=tail length, TC=tail circumference, CBC=cannon bone circumference, CBL=cannon bone length, SC=scrotal circumference.

Body length had a strong positive correlation coefficient with heart girth (r = 0.76, 0.72, 0.80, and 0.89) in Dorper, Karakul, Meat-master, and Tswana sheep males, respectively, while Damara males had significant (p<0.05), moderate, positive associations between body length and heart girth (r = 0.66). The current findings are consistent with Selala & Tyasi (2022), and Becker (2021) who found strong positive associations between body length and heart girth (r = 0.78, 0.73) in Dorper and Meat-master rams, respectively. However, the association between body length and heart girth of Tswana males in this study was much higher than those reported by Bolowe *et al.* (2021). The body length of Dorper and Tswana males had the highest strong positive and significant (p<0.05) correlations with shoulder width (r =0.81, and 0.99, respectively), while significant (p<0.05), moderate and positive associations were observed between body length and rump width (r = 0.65, 0.69, and 0.64) in Damara, Dorper, and Meat-master males, respectively. Rump height (r = -0.50) and cannon bone circumference (r = -0.44) of Karakul males had non-significant (p>0.05), moderate, and negative correlations with body length. This indicates that selecting for long-bodied Karakul males will result in animals with low rump height and cannon bone circumference. A negatively strong non-significant (p>0.05) association was observed between body length and cannon bone circumference (r = -0.86), and positively strong non-significant (p>0.05) correlations occurred between body length and cannon bone length (r = 0.91) and scrotal circumference (r = 0.82) of Tswana males. Bolowe *et al.* (2021) found moderate positive associations between body length and cannon bone circumference and cannon bone length (r = 0.49, and 0.52, respectively) in Tswana sheep males.

Heart girth had strong positive associations with shoulder width (r = 0.87, 0.84, and 0.94), rump height (r = 0.76, 0.83, and 0.83), rump width (r = 0.77, 0.85, and 0.99), and moderate positive associations with scrotal circumference (r = 0.68, 0.52, and 0.50) in Damara, Dorper, and Tswana sheep males, respectively. Selala & Tyasi (2022) found moderate associations between heart girth and rump height (r = 0.66) in Dorper rams of South Africa. Tail circumference and cannon bone circumference of Damara and Meat-master males had significant (p<0.05), high positive correlations, while tail length had significant (p<0.05), moderate correlations with heart girth.

Mavule (2012) also found high, positive associations between heart girth and tail circumference of Zulu sheep in KwaZulu-Natal. The moderate correlation coefficient between heart girth and cannon bone length (r = 0.69) in Dorper males found in the current study is consistent with Mohammed *et al.* (2018) (r = 0.52) in Dorper rams of Ethiopia.

Cannon bone circumference had non-significant (p>0.05) negative correlations with other linear body measurements like shoulder width (r = -0.11, and -0.78), rump width (r = -0.17, and -0.41), neck length (r = -0.58, and -0.87) in Karakul and Tswana males, respectively. A non-significant (p>0.05) negative association was also found between cannon bone circumference and cannon bone length (r = -0.62) in Tswana males.

4.4.2 Phenotypic correlations between body weight and linear body measurements in females

Positive and significant (p<0.05) correlations were observed between body weight and all other linear body measurements for all the female sheep breeds except for the association between body weight and cannon bone circumference in Meat-master females (Table 4.2). The highest, strong, positive and significant (p<0.05) associations occurred between body weight and heart girth (r = 0.90, 0.76, 0.80, 0.72, and 0.83), while the lowest non-significant (p>0.05) and weak associations were observed between body weight and cannon bone circumference (r = 0.003, 0.11, 0.11, -0.023, and 0.07) in Damara, Dorper, Karakul, Meat-master, and Tswana females, respectively. The findings are consistent with Mohammed *et al.* (2018), Becker (2021), Bolowe *et al.* (2021) and Castillo *et al.* (2023) who reported higher positive correlations in females between body weight and heart girth in Dorper and local breeds of Ethiopia, Meat-master in South Africa, Tswana in Botswana, and Socorro Island Merino in Mexico, respectively. On the contrary, Rotimi *et al.* (2020) and Selala & Tyasi (2022) reported a much higher correlation between body weight and body length compared to body weight and heart girth in female Sahelian goats of Nigeria, and Dorper lambs of South Africa, respectively. This suggests that heart girth and body length can be used to indirectly select body weight and are good parameters that can be used to accurately estimate body weight in the absence of weighing scales. In the current study however, weak positive associations between body weight and body length (r = 0.39, 0.32, and 0.13), and between body weight and shoulder width (r = 0.33, 0.34, and 0.32) were found in Dorper, Karakul, and

Tswana females, respectively. Weak, positive correlation coefficients were observed between body weight and neck length in all sheep breeds.

Table 4.2. Phenotypic correlations between body weight and other morphometric traits in females of different sheep breeds

Breed	Trait	BW	BL	HG	HW	SW	RH	RW	NL	TL	TC	CBC	CBL
Damara	BW	1	0.576*	0.903*	0.652*	0.519*	0.512*	0.418*	0.301*	0.196	0.488*	0.003	0.193
Dorper		1	0.389*	0.764*	0.411*	0.329*	0.446*	0.579*	0.248*	0.0	0.0	0.11	0.306*
Karakul		1	0.320*	0.800*	0.215*	0.339*	0.287*	0.248*	0.222	0.0	0.0	0.106	0.186*
Meat-master		1	0.535*	0.717*	0.529*	0.501*	0.460*	0.210*	0.344*	0.297*	0.516*	-0.023	0.403*
Tswana		1	0.128	0.828*	0.473*	0.319	0.155	0.423*	0.12	0.0	0.0	0.072	0.182
Damara	BL		1	0.619*	0.564*	0.528*	0.402*	0.434*	0.276	0.225	0.147	0.007	0.25
Dorper			1	0.417*	0.371*	0.319*	0.386*	0.364*	0.229*	0.0	0.0	-0.007	0.266
Karakul			1	0.188*	0.473*	0.407*	0.384*	-0.177	0.539*	0.0	0.0	-0.249	0.335*
Meat-master			1	0.494*	0.524*	0.312*	0.519*	0.241*	0.219*	0.352*	0.432*	0.122	0.259*
Tswana			1	0.207	0.488*	-0.11	0.372*	0.294	0.068	0.0	0.0	0.21	-0.192
Damara	HG			1	0.718*	0.532*	0.610*	0.567*	0.235	0.104	0.351*	0.103	0.187
Dorper				1	0.283*	0.071	0.390*	0.481*	-0.016	0.0	0.0	0.324*	0.124
Karakul				1	0.154	0.200*	0.240*	0.307*	-0.007	0.0	0.0	0.242*	-0.025
Meat-master				1	0.302*	0.213*	0.347*	0.492*	-0.019	0.175	0.371*	0.303*	0.155
Tswana				1	0.411*	0.324	0.302	0.335	0.176	0.0	0.0	0.165	0.026
Damara	HW				1	0.567*	0.746*	0.487*	0.117	0.338*	0.253	0.117	0.262
Dorper					1	0.447*	0.626*	0.397*	0.516*	0.0	0.0	-0.273	0.441*
Karakul					1	0.387*	0.833*	-0.27	0.522*	0.0	0.0	-0.263	0.465*
Meat-master					1	0.472*	0.749*	-0.036	0.489*	0.311*	0.433*	-0.22	0.483*
Tswana					1	-0.085	0.488*	0.584*	0.304	0.0	0.0	0.443*	-0.007
Damara	SW					1	0.612*	0.198	0.205	0.346*	0.092	-0.045	0.246
Dorper						1	0.462*	0.410*	0.810*	0.0	0.0	-0.57	0.611*
Karakul						1	0.304*	-0.214	0.712*	0.0	0.0	-0.286	0.275*
Meat-master						1	0.280*	-0.263	0.682*	0.337*	0.562*	-0.552	0.572*
Tswana						1	0.032	0.147	0.057	0.0	0.0	-0.114	0.460*
Damara	RH						1	0.351*	0.094	0.256	0.316*	0.083	0.053
Dorper							1	0.415*	0.464*	0.0	0.0	-0.159	0.348*
Karakul							1	-0.228	0.365*	0.0	0.0	-0.199	0.375*
Meat-master							1	0.033	0.237*	0.273*	0.458*	0.009	0.351*
Tswana							1	0.409*	-0.154	0.0	0.0	0.634*	-0.172
Damara	RW							1	-0.337	-0.155	-0.033	0.588*	0.133
Dorper								1	0.278*	0.0	0.0	0.01	0.337*
Karakul								1	-0.463	0.0	0.0	0.571*	-0.201
Meat-master								1	-0.568	-0.161	-0.042	0.700*	-0.327
Tswana								1	0.339	0.0	0.0	0.274	-0.007
Damara	NL								1	0.407*	0.303*	-0.757	0.113
Dorper									1	0.0	0.0	-0.738	0.672*
Karakul									1	0.0	0.0	-0.492	0.488*
Meat-master									1	0.459*	0.406*	-0.728	0.639*

Tswana		1	0.0	0.0	0.103	-0.038
Damara	TL		1	0.251	-0.428	0.453*
Dorper			0.0	0.0	0.0	0.0
Karakul			0.0	0.0	0.0	0.0
Meat-master			1	0.265*	-0.284	0.374*
Tswana			0.0	0.0	0.0	0.0
Damara	TC			1	-0.248	-0.31
Dorper				0.0	0.0	0.0
Karakul				0.0	0.0	0.0
Meat-master				1	-0.145	0.362*
Tswana				0.0	0.0	0.0
Damara	CBC				1	0.016
Dorper					1	-0.533
Karakul					1	-0.161
Meat-master					1	-0.442
Tswana					1	-0.232
Damara	CBL					1
Dorper						1
Karakul						1
Meat-master						1
Tswana						1

*=p≤0.05, BW=body weight, BL=body length, HG=heart girth, HW=height at withers, SW=shoulder width, RH=rump height, RW=rump width, NL=neck length, TL=tail length, TC=tail circumference, CBC=cannon bone circumference, CBL=cannon bone length.

There was a moderate, positive and significant ($p<0.05$) correlation between body length and linear body measurements like heart girth (r = 0.62, and 0.49), height at withers (r = 0.56, and 0.52), shoulder width (r = 0.53, and 0.31), rump height (r = 0.40, and 0.52) in Damara and Meat-master females, respectively. Body length had a weak, positive correlation coefficient with traits such as neck length (r = 0.28, and 0.22) and tail length (r = 0.0.23, and 0.35) in Damara and Meat-master females, respectively. The weak associations between body length and neck length, and tail length are consistent with Becker (2021) who found weak correlations between body length and neck length, and tail length of Meat-master ewes. Weak, negative and significant ($p<0.05$) associations between body length and rump width (r = -0.18) and between body length and cannon bone circumference (r = -0.25) were found in Karakul females, while cannon bone length (r = -0.192) had negatively weak non-significant ($p>0.05$) correlations with body length in Tswana females.

The highest, positive, and significant ($p<0.05$) correlation coefficient was observed between heart girth and height at withers (r = 0.72), followed by heart girth and rump height (r = 0.61), heart girth and rump width (r = 0.57) and heart girth and shoulder width (r = 0.53) in Damara females. Michael *et al.* (2016) reported the highest correlation between heart girth and rump width (r = 0.45), followed by heart girth and height at withers (r = 0.38) and heart girth and cannon bone circumference (r = 0.36) in indigenous sheep ewes of Northern Ethiopia. Weak correlation coefficients between heart girth and height at withers (r = 0.28, 0.15, 0.30, and 0.41), heart girth and shoulder width (r = 0.07, 0.20, 0.21, and 0.32), heart girth and rump height (r = 0.39, 0.24, 0.35, and 0.30), heart girth and rump width (r = 0.48, 0.31, 0.49, and 0.34), heart girth and neck length (r = -0.016, -0.007, -0.019, and 0.117) were found in Dorper, Karakul, Meat-master, and Tswana females, respectively. Cannon bone length also had weak associations with heart girth, height at withers, rump height, and rump width in Damara, Dorper, Karakul, Meat-master, and Tswana females. Mohammed *et al.* (2018) also reported a weak association between cannon bone length and rump width (r = 0.35) in purebred Dorper ewes of Ethiopia. Bolowe *et al.* (2021) reported moderate, positive, and significant correlations between cannon bone length and other morphometric traits such as heart girth (r = 0.51), height at withers (r = 0.54), and rump height (r = 0.57) in Tswana ewes. Significantly ($p<0.05$) strong and positive correlations were observed between height at withers and rump height (r = 0.83) in Karakul, and between shoulder width and neck length (r = 0.81) in Dorper females. Strong, significant ($p<0.05$) and negative correlations occurred between neck length and cannon bone circumference (r = -0.76, -0.74, and -0.73) in Damara, Dorper, and Meat-master females, respectively. This implies that selecting female sheep with longer necks may consequently result in sheep with thin cannon bones usually associated with indigenous sheep breeds to help them walk long distances in search of pastures. However, thin cannon bones in meat animals like Dorper and Meat-master may be disadvantageous as the cannon bones would not be able to carry the weight of the animal, hence being prone to breakage and fractures.

4.4.3 Prediction of body weight using morphometric traits for Dorper females

Body weight is a very crucial trait in animal husbandry as it determines animal management practices like feeding and drug dosage (Rotimi *et al.*, 2020). One of the ways that can be used to estimate the body weight of sheep is the use of independent linear body measurements to develop prediction models (Table 4.3). Heart girth had the highest correlation with body weight (r = 0.76) in Dorper females, and as such it was the first independent trait to be fitted into the model. Heart girth alone had a coefficient of determination (R^2) of 0.53, which means 53% of the variability in body weight of female Dorper was described by heart girth. Selala & Tyasi (2022) reported a positively high correlation between body weight and heart girth, with heart girth explaining about 66% of the variation in body weight of female Dorper. As more independent traits were added, the coefficient of determination kept on increasing and this is consistent with Getachew *et al.* (2009) who highlighted that R^2 increases with additional new independent variables to the model. When adding new variables to the model, only those independent traits that increase the coefficient of determination should be retained while those causing a decrement should be removed from the model (Getachew *et al.*, 2009). The body weight of female Dorper can be estimated using the prediction equation y = -102.29+0.26HG – 0.77HW+0.34BL+4.71NL+3.61CBL, where y is the dependent body weight and HG, HW, BL, NL, CBL are independent heart girth, height at withers, body length, neck length, and cannon bone length, respectively. The prediction equation was selected based on the highest coefficient of determination ($R^2 = 0.95$), together with the adjusted coefficient of determination (Adj $R^2 = 0.89$).

Table 4.3. Multiple regression analysis of body weight with linear body measurements for Dorper females

	Parameters								
Model	Inter	β_1	β_2	β_3	β_4	β_5	β_6	R^2	Adj R^2
HG	-13.80	0.76	-	-	-	-	-	0.53	0.47
HG+HW	70.61	1.11	-1.96	-	-	-	-	0.75	0.68
HG+HW+BL	30.03	1.08	-2.02	0.65	-	-	-	0.85	0.77
HG+HW+BL+NL	-33.88	0.58	-1.54	0.64	3.33	-	-	0.91	0.84
HG+HW+BL+NL+CBL	**-102.29**	**0.26**	**-0.77**	**0.34**	**4.71**	**3.61**	**-**	**0.95**	**0.89**
HG+HW+BL+NL+CBL+CBC	-60.46	0.49	-1.20	0.55	5.10	1.48	-4.21	0.96	0.89

Inter= intercept, HG=heart girth, HW=height at withers, BL=body length, NL=neck length, CBL=cannon bone length, CBC=cannon bone circumference.

4.4.4 Prediction of body weight using morphometric traits for Dorper males

Independent linear body measurements like heart girth, height at withers, neck length and cannon bone length were found to be fit for the development of prediction models for the estimation of Dorper males (Table 4.4) and this is consistent with Getachew *et al.* (2009) who also included heart girth and height at withers in prediction equations for Menz rams in Ethiopia. Heart girth alone explained 54% variability of the model, which is lower when compared to Mohammed *et al.* (2018) and Selala & Tyasi (2022) who reported that heart girth accounted for 86% and 79% variability in body weight of Dorper rams, respectively. The use of heart girth with height at withers increased the coefficient of determination (R^2) from 0.54 to 0.64 and this is consistent with Kunene (2010) who found that including heart girth and height at withers in the model increased R^2 from 0.54 to 0.81 compared to the use of the individual traits in Zulu sheep with two pairs of permanent incisors. Since the inclusion of cannon bone length in the model resulted in a small increment of R^2 (0.68-0.70) and a decrement in the adjusted coefficient of determination (0.63-0.62), a prediction equation that excluded cannon bone length was selected. As such, the body weight of Dorper males can be estimated using the prediction equation y = -20.13+0.71HG+1.09HW – 2.05NL, where y is the body weight and HG, HW, and NL are heart girth, height at withers and neck length, respectively.

Table 4.4. Multiple regression analysis of body weight with linear body measurements for Dorper males

	Parameters						
Model	Inter	β_1	β_2	β_3	β_4	R^2	Adj R^2
HG	-15.56	0.87	-	-	-	0.54	0.52
HG+HW	-44.75	0.62	0.86	-	-	0.64	0.60
HG+HW+NL	**-20.13**	**0.71**	**1.09**	**-2.05**	**-**	**0.68**	**0.63**
HG+HW+NL+CBL	-6.02	0.68	1.15	-2.05	-1.20	0.70	0.62

Inter= intercept, HG=heart girth, HW=height at withers, NL=neck length, CBL=cannon bone length.

4.4.5 Prediction of body weight using morphometric traits for Karakul females

Heart girth produced fairly good body weight prediction (R^2 = 0.60) for Karakul females, but as more traits were added, there was an increase in the coefficient of determination (Table 4.5). The coefficient of determination increased to 0.68 when heart girth and height at withers were included in the model and this is consistent with Kunene (2010) who found an increment to 0.73 in the R^2 when heart girth and height at withers were used to develop regression equations for Zulu sheep with milk teeth. Cannon bone length contributed to a major increase in the prediction model, and this resulted in the model accounting for 84% of the variability in body weight of Karakul females. On the contrary, Mahmud *et al.* (2014) reported a negative correlation between body weight and cannon bone length of Nigerian breeds of sheep aged one year and below, which resulted in cannon bone length being excluded from the body weight prediction equation of Nigerian breeds of sheep. The model with a higher R^2 (0.84) and adjusted coefficient of determination (Adj R^2 = 0.76) was the one that included heart girth, height at withers and cannon bone length. This means that the body weight of Karakul females can be estimated based on the prediction equation y = -

107.08+0.58HG+0.69HW+5.58CBL, where y is the body weight and HG, HW, and CBL are heart girth, height at withers and cannon bone length, respectively.

Table 4.5. Multiple regression analysis of body weight with linear body measurements for Karakul females

	Parameters						
Model	Inter	β_1	β_2	β_3	β_4	R^2	Adj R^2
HG	-36.27	0.98	-	-	-	0.60	0.55
HG+HW	-68.26	0.92	0.59	-	-	0.68	0.59
HG+HW+CBL	**-107.08**	**0.58**	**0.69**	**5.58**	**-**	**0.84**	**0.76**
HG+HW+CBL+CBC	-110.19	0.50	0.60	5.13	2.75	0.85	0.72

Inter= intercept, HG=heart girth, HW=height at withers, CBL=cannon bone length, CBC=cannon bone circumference.

4.4.6 Prediction of body weight using morphometric traits for Karakul males

Heart girth alone explained 75% of the variability in body weight of Karakul males (Table 4.6) and this is consistent with Getachew *et al.* (2009) who found the coefficient of determination of heart girth to be 0.76 and 0.74 for Menz and Afar rams, respectively. This indicates that heart girth can be used as the sole predictor of body weight for Karakul males. Similar results where heart girth had higher R^2 (0.78 and 0.86) were found by Mavule (2012) and Mohammed *et al.* (2018) in regression equations for Zulu rams and cross-bred Ethiopian rams, respectively. Heart girth and body length accounted for 85% of the variability in body weight of Karakul males and these results are much higher as compared to those found by Younas *et al.* (2013) when heart girth and body length were used in the model (R^2 = 0.69) for Hissardale sheep. Scrotal circumference caused an increment in R^2 (0.93) when added to heart girth and body length. Kunene (2010) reported that scrotal circumference can be used to precisely estimate the body weight of Zulu rams who are under 22 months of age. The best prediction equation that can be used for the estimation of Karakul male body weight is y = -137.20+1.60HG+0.41BL+0.61SC, where y is the body weight and HG, BL, SC are heart girth, body length and scrotal circumference, respectively.

Table 4.6. Multiple regression analysis of body weight with linear body measurements for Karakul males

	Parameters					
Model	Inter	β_1	β_2	β_3	R^2	Adj R^2
HG	-105.50	1.73	-	-	0.75	0.68
HG+BL	-125.06	1.46	0.64	-	0.85	0.75
HG+BL+SC	**-137.20**	**1.60**	**0.41**	**0.61**	**0.93**	**0.81**

Inter=intercept, HG=heart girth, BL=body length, SC=scrotal circumference.

4.4.7 Prediction of body weight using morphometric traits for Meat-master females

A fairly low coefficient of determination (R^2 = 0.46) and adjusted coefficient of determination (Adj R^2 = 0.39) were found when heart girth was fitted alone into the model, but as more parameters were added the R^2 and Adj R^2 also increased (Table 4.7). These findings are consistent with Michael *et al.* (2016) who noted a higher Adj R^2 when more than one parameter was used for the regression equation of East Gojam Zone sheep in Ethiopia. A major increment was found when body length was added to heart girth and this means that heart girth and body length can be used as the only parameters to estimate body weight of Meat-master females. The use of only a few parameters when estimating body weight has been reported by Michael *et al.* (2016) and Bolowe *et al.* (2021) to be the most preferred under field conditions for simplicity as animal handling may be difficult, hence high chances of errors when measuring more variables. However, including more independent variables in a regression equation has been reported by Getachew *et al.* (2009) to increase precision and accuracy when estimating the body weight of sheep. The best-fitted model which can be used for the estimation of body weight for Meat-master females is y = -102.11+1.02HG+1.00BL – 1.71CBL+0.75NL, where y is the dependent body weight and HG, BL, CBL, NL are independent heart girth, body length, cannon bone length and neck length, respectively.

Table 4.7. Multiple regression analysis of body weight with linear body measurements for Meat-master females

		Parameters					
Model	Inter	β_1	β_2	β_3	β_4	R^2	Adj R^2
HG	-34.25	0.99	-	-	-	0.46	0.39
HG+BL	-129.62	1.18	1.10	-	-	0.86	0.82
HG+BL+CBL	-101.45	1.13	1.00	-1.14	-	0.92	0.88
HG+BL+CBL+NL	**-102.11**	**1.02**	**1.00**	**-1.71**	**0.75**	**0.95**	**0.91**

Inter= intercept, HG=heart girth, BL=body length, NL=neck length, CBL=cannon bone length.

4.4.8 Prediction of body weight using morphometric traits for Meat-master males

Traits like heart girth, height at withers, scrotal circumference, neck length, and cannon bone length were found fit to predict the body weight of Meat-master males as they contributed to an increase in the coefficient of determination (R^2) and adjusted coefficient of determination (Adj R^2) (Table 4.8). The prediction model which included all the independent variables had the highest R^2

(0.70) and Adj R^2 (0.57), and this indicates that the prediction equation explained 70% of the variability in body weight of Meat-master males. The findings are consistent with Abera *et al.* (2014) who reported Adj R^2 of 0.57 when heart girth, body length and height at withers were fitted in a prediction model to estimate the body weight of sheep breeds found in the Selale area, Ethiopia. The addition of cannon bone length to the prediction model resulted in a small increment of R^2 from 0.67 to 0.70, while Adj R^2 remained the same (0.57). This means that any of the models with or without the cannon bone length can be used to estimate the body weight of Meat-master males as cannon bone length does not contribute much difference. Therefore, the body weight of Meat-master males can be estimated based on the prediction equation y = 16.45+0.42HG+0.79HW+0.34SC – 2.05NL, where y is the body weight and HG, HW, SC, NL, CBL are heart girth, height at withers, scrotal circumference, neck length, and cannon bone length, respectively.

Table 4.8. Multiple regression analysis of body weight with linear body measurements for Meat-master males

	Parameters							
Model	Inter	β_1	β_2	β_3	β_4	β_5	R^2	Adj R^2
HG	9.56	0.64	-	-	-	-	0.41	0.37
HG+HW	-20.29	0.54	0.56	-	-	-	0.49	0.42
HG+HW+SC	-25.55	0.46	0.50	0.57	-	-	0.56	0.46
HG+HW+SC+NL	**16.45**	**0.42**	**0.79**	**0.34**	**-2.05**	**-**	**0.67**	**0.57**
HG+HW+SC+NL+CBL	5.59	0.39	0.83	0.33	-2.17	0.93	0.70	0.57

Inter=intercept, HG=heart girth, HW=height at withers, SC=scrotal circumference, NL=neck length, CBL=cannon bone length.

4.4.9 Prediction of body weight using morphometric traits for Damara females

Heart girth accounted for a high proportion of changes in body weight of Damara females (R^2 = 0.77) (Table 4.9) and this is consistent with Mavule (2012) who reported that heart girth alone explained 77.5% of the variation in body weight of young Zulu sheep. This indicates that heart girth can be used as a sole predictor of body weight for Damara females. Kunene (2010) indicated that the high association between body weight and heart girth may be attributed to the fact that heart girth is made up of muscles, bones and viscera which contribute mainly to the body weight of an animal. However, on the contrary, Selala & Tyasi (2022) reported the highest coefficient of determination in body length and this indicates that body length explained the most variation in body weight of Dorper lambs in South Africa. As more variables were fitted into the model, the

R^2 increased slightly, but there was a decrease in Adj R^2. This indicated that the added variables did not contribute much to the model. However, adding all the parameters gave a perfectly fit model (R^2 = 1.0 and Adj R^2 = 0.99) and this is in agreement with Abera *et al.* (2014) and Michael *et al.* (2016) who highlighted that fitting more independent variables in the prediction equation increase the R^2, hence an increase in accuracy. The best prediction equation for body weight of Damara females is y = 77.80 – 0.48HG – 3.12HW – 8.38BL – 6.06NL+25.44CBL+66.26CBC, where y is the body weight and HG, HW, BL, NL, CBL, CBC are heart girth, height at withers, body length, neck length, cannon bone length and cannon bone circumference, respectively.

Table 4.9. Multiple regression analysis of body weight with linear body measurements for Damara females

				Parameters					
Model	Inter	β_1	β_2	β_3	β_4	β_5	β_6	R^2	Adj R^2
HG	-25.20	0.80	-	-	-	-	-	0.77	0.73
HG+HW	-34.62	0.78	0.17	-	-	-	-	0.78	0.69
HG+HW+CBC	-54.90	0.47	0.32	4.88	-	-	-	0.81	0.67
HG+HW+BL+NL+CBL+CBC	**77.80**	**-0.48**	**-3.12**	**-8.38**	**-6.06**	**25.44**	**66.26**	**1.00**	**0.99**

Inter=intercept, HG=heart girth, HW=height at withers, CBC=cannon bone circumference, NL=neck length, CBL=cannon bone length.

4.4.10 Prediction of body weight using morphometric traits for Damara males

Body length and heart girth accounted for 87% of the variability when fitted in the model used to predict the body weight of Damara males than when the traits were fitted individually (Table 4.10). This indicates that body length and heart girth can be used to reliably predict the body weight of Damara males. The findings are consistent with Younas *et al.* (2013) who reported that body length and heart girth are the best fit for the prediction equation for body weight in Hissardale sheep. The high coefficient of determination may be attributed to the fact that body length measures the skeleton of the animal while heart girth contains both the bones and muscles, meaning a combination of both traits will contribute more to the changes in body weight (Kunene, 2010). Rotimi *et al.* (2020) found that paunch girth and body length had the highest contribution to the body weight of Sahelian goats when compared to other traits. This means that body length and heart girth can be used during breeding to select for body weight. The body weight of Damara males can be predicted based on the prediction equation y = -1063.34+8.02HG+0.86HW+4.64BL, where y is the dependent body weight and HG, HW, BL are independent variables heart girth, height at withers, and body length, respectively.

Table 4.10. Multiple regression analysis of body weight with linear body measurements for Damara males

	Parameters						
Model	Inter	β_1	β_2	β_3	β_4	R^2	Adj R^2
HG+BL	-777.56	6.27	3.75	-	-	0.87	0.84
HG+HW+BL	**-1063.34**	**8.02**	**0.86**	**4.64**	**-**	**0.99**	**0.98**
HG+HW+BL+NL	-1350.82	10.68	2.03	5.35	-3.60	1.00	1.00
HG+HW+BL+CBC	-724.97	4.45	1.34	1.89	18.00	1.00	1.00
HG+HW+BL+SC	-1054.84	7.93	0.73	4.57	0.50	1.00	1.00

Inter= intercept, HG=heart girth, HW=height at withers, BL=body length, NL=neck length, CBL=cannon bone circumference, SC=scrotal circumference.

4.5 Conclusion

There was a strong, significant, positive correlation between body weight and heart girth, body length, and shoulder width in all the males across the different sheep breeds, except for Karakul males which had a non-significant moderate correlation between body weight and heart girth. The highest positive correlation was found between body weight and heart girth of all the female sheep breeds. From the independent traits that were used to develop prediction equations of different breeds, heart girth accounted for more variability in body weight of almost all the sheep breeds, irrespective of sex. Independent traits like height at withers and body length also caused an increase in the coefficient of determination across various sheep breeds. Body weight can be indirectly selected, through a selection of heart girth, height at withers and body length.

4.6 References

Abera, B., Kebede, K., Gizaw, S., & Feyera, T. (2014). On-Farm Phenotypic Characterization of Indigenous Sheep Types in Selale Area, Central Ethiopia. *Veterinary Science and Technology, 5* (3), 1-6.

Becker, S.J. (2021). Phenotypic characterisation of Meatmaster sheep using quantitative and qualitative trait analysis. *Masters thesis.* Central University of Technology. Free State, South Africa.

Bolowe, M.A., Thutwa, K., Kgwatalala, P.M., Monau, P.I., & Malejane, C. (2021). Phenotypic characterization of indigenous Tswana sheep population in selected Districts of Southern Botswana. *African Journal of Agricultural Research, 17* (10), 1268-1280.

Castillo, P.E., Macedo, R.J., Arredondo, V., Zepeda, J.L., Valencia-Posadas, M., & Haubi, C.U. (2023). Morphological Description and Live Weight Prediction from Body Measurements of Socorro Island Merino Lambs. *Animals,* 13, 1-11.

FAO. (2012). Phenotypic characterization of Animal Genetic Resources. url: www.fao.org/docrep/015/ i2686e/i2686e00.pdf.

Getachew, T., Haile, A., Tibbo, M., Sharma, A.K., Sölkner, J., Wurzingere, M., & Terefe, E. (2009). Use of linear body measurements for performance recording and genetic evaluation of Menz and Afar sheep breeds under village condition. *Ethiopian Society of Animal Production,* 17, 114-121.

Kgaudi, K. (2014). Milk production potential and major browse species consumed by dromedary camels (Camelus dromedarius) in Tsabong area, Southern Kgalagadi District. BSc Dissertation, Botswana College of Agriculture, Gaborone, Botswana.

Kunene, N.W. (2010). Characterization of indigenous Zulu (Nguni) sheep for utilization, improvement and conservation. *Doctor of Philosophy Dissertation*. University of KwaZulu-Natal, South Africa.

Mahmud, M.A., Shaba, P., Abdulsalam, W., Yisa, H.Y., Gana, J., Ndagi, S., & Ndagimba, R. (2014). Live body weight estimation using cannon bone length and other body linear measurements in Nigerian breeds of sheep. *Journal of Advanced Veterinary and Animal Research, 1* (4), 169-176.

Mavule, B.S. (2012). Phenotypic characterization of Zulu sheep: Implications for conservation and improvement. *Masters Dissertation*. University of Zululand, South Africa.

Michael, A., Kefelegn, K., & Yoseph, M. (2016). Phenotypic Characterization of Indigenous Sheep Types in Northern Ethiopia. *Journal of Natural Sciences Research, 6* (15), 16-27.

Mohammed, J., Abegaz, S., Lakew, M., & Tarekegn, G.M. (2018). Phenotypic Characterization of Dorper, Local Sheep and Their Crossbred Sheep Population in North Eastern Amhara, Ethiopia. *Journal of Biology, Agriculture and Healthcare, 8* (1), 15-25.

Rotimi, E.A., Momoh, O.M., & Egahi, J.O. (2020). Relationship between bodyweight and morphological traits in Sahelian goats of Nigeria using path analysis. *Journal of Agricultural Sciences, 25* (3), 455-460.

Sebolai, B., Nsoso, S. J., Podisi, B., & Mokhutshwane, B. S. (2012). The estimation of live weight based on linear traits in indigenous Tswana goats at various ages in Botswana. *Tropical Animal Health Production, 44* (4), 899-904.

Seifu, E., Madibela, O.R., & Teketay, D. (2019). Camels in Botswana: Herd dynamics and future development implications. *Botswana Journal of Agriculture and Applied Sciences, 13* (1), 12-25.

Selala, L.J., & Tyasi, T.L. (2022). Using Morphological Traits to Predict Body Weight of Dorper Sheep Lambs. *World Veterinary Journal, 12* (1), 66-73.

Temoso, O., Coleman, M., Baker, D., Morley, P., Baleseng, L., Makgekgenene, A., & Bahta, S. (2017). Using path analysis to predict body weight from body measurements of goats and sheep of communal rangelands in Botswana. *South African Journal of Animal Science, 47* (6), 854-863.

Younas, U., Abdullah, M., Bhatti, J.A., Pasha, T.N., Ahmad, N., Nasir, M., & Hussain, A. (2013). Inter-relationship of body weight with linear body measurements in Hissardale sheep at different stages of life. *Journal of Animal and Plant Sciences,* 23, 40-44.

CHAPTER 5

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General Discussion

Variations in environmental and management conditions result in a diversity of animal genetic resources within and between different sheep breed populations. Understanding different breed populations found in Botswana plays a major role in breed conservation and the development of breed improvement strategies. Phenotypic characterization is a pre-requisite for sustainable utilization of the sheep genetic resources found in Botswana. The main aim of the study was to phenotypically characterize, estimate correlation coefficients for body weight and linear body measurements, and develop body weight prediction equations from linear body measurements for different sheep breeds found in Botswana (Tswana, Dorper, Damara, Meat-master, and Karakul).

Phenotypic characterization includes qualitative and quantitative traits, together with the production environment (Becker, 2021). Exotic sheep breeds (Dorper, Meat-master, and Karakul) were superior in traits of economic importance like body weight, heart girth and body length as compared to their indigenous counterparts (Tswana and Damara), which had smaller dimensions in body weight and most linear body measurements. However, indigenous sheep breeds indicated superiority in adaptive traits like long, thin cannon bones and light body weight which makes it easier for them to flee from danger and walk long distances in search of pasture. Also, indigenous sheep breeds were characterized by fat tails which store fats that are utilized during periods of feed scarcity (Almeida, 2011). Again, the dominant white coat color in Tswana sheep helps it during hot temperatures to reflect solar radiation, while the brown coat color helps Damara sheep to camouflage with the local topology when hiding from predators. This indicates that indigenous sheep breeds are more adaptable to harsh local environmental conditions than exotic breeds. Even though farmers are currently more interested in exotic breeds due to their traits of economic importance, the issue of global warming continues to be a concern. According to Feleke *et al.* (2016), as global warming increases, there will be a decline in the amount of rainfall which may result in feed scarcity and more frequent and intense drought. During feed scarcity, indigenous sheep breeds will be at an advantage because of their small body frame which requires less feed as compared to their exotic counterparts. As such, it is important to conserve our local indigenous sheep breeds for future utilization in response to climate change and possible changes in consumer or market demands.

Linear body measurements like heart girth, body length and height at withers had higher correlations with body weight, which means the aforementioned traits can be used to indirectly select for body weight in sheep. The weighing band is commonly used to estimate the body weight of animals in the absence of weighing scales, however, current results indicate that it does not provide accurate estimations as compared to prediction equations. As such, prediction equations were developed to estimate the body weight of different sheep breeds using morphometric traits which can be easily measured using a measuring tape. Accurate body weights are essential for marketing and pricing of small stock.

5.2 Conclusions

Tswana sheep is characterized by a patchy coat color pattern with a white dominant coat color, semi-pendulous ears, and the absence of horns in both sexes. Dorper sheep is plain with a black head and white body, horizontal ears, and absence of horns and wattle in both sexes. Karakul sheep have long smooth hair with black coat color, while Damara and Meat-master sheep breeds are brown in coat color and have straight long fat and moderate tails, respectively. Breed and sex had a significant influence on body weight and most linear body measurements of all the sheep breeds. There was sexual dimorphism with most traits favoring males than females. Generally, Dorper, Meat-master, and Karakul sheep breeds showed superiority in most traits of economic importance compared to Damara and Tswana sheep breeds. Positive phenotypic correlations were found between body weight and most linear body measurements in all the breeds. Heart girth had the highest correlation with body weight across all the breeds, irrespective of sex. As such, heart girth was included in all the prediction models used to estimate the body weight of different sheep breeds because of its highest correlation with body weight. More than one independent trait was used for the construction of prediction equations to increase the accuracy of the prediction equations.

5.3 Recommendations

1) Breeders should consider both qualitative and quantitative traits of different sheep breeds when developing breed improvement programs to avoid the loss of some important adaptive traits.

2) The use of prediction equations compared to the weighing band is recommended, since prediction equations provide closer results to the actual body weight than the use of the weighing band.
3) It is recommended that the study should be extended to cover the whole sheep population including those in the extensive management system.
4) Further research on the estimation of heritability of linear body measurements across different sheep breeds in Botswana should be explored.

5.4 References

Almeida, A.M. (2011). The Damara in the context of Southern Africa fat-tailed sheep breeds. *Tropical Animal Health Production,* 43, 1427-1441.

Becker, S.J. (2021). Phenotypic characterisation of Meatmaster sheep using quantitative and qualitative trait analysis. *Masters thesis.* Central University of Technology. Free State, South Africa.

Feleke, F.B., Berhe, M., Gebru, G., & Hoag, D. (2016). Determinants of adaptation choices to climate change by sheep and goat farmers in Northern Ethiopia: the case study of Southern and Central Tigray, Ethiopia. *SpringerPlus,* 5, 1692.