Nutritional status of Tswana sheep: evaluation of feeding practices and prospects of utilizing protein sources to improve performance

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DECLARATION

I, Moemedi Dikakanyo Legodimo, declare that the thesis hereby submitted by me for the degree of Doctor of Philosophy in Agriculture in Animal Science at the North-West University is my own original and independent research work. The thesis was carried out under the supervision of Dr L. Motsei and Prof U. Marume. This thesis or any part of it has not been previously submitted by me for any degree or examination to another faculty or University. The research work reported in this thesis does not contain any person's data, pictures, graphs or other information unless specifically acknowledged as being sourced from those persons. I, furthermore, cede the copyright of this dissertation in favour of the North-West University

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GENERAL ABSTRACT

This study was conducted 1) to identify the main feed resources and feeding methods used by small-holder sheep farmers; 2) to determine the nutritional and health status of sheep grazing in communal rangelands and 3) to determine the best cost effective protein source to use for market lambs as a replacement for soybean meal (SBM). The study evaluated the nutrient intake, digestibility, utilization, blood metabolites, performance, carcass traits and meat quality of Tswana lambs fed cereal stover-based diets containing increasing levels of canola meal (CM) and sunflower seed cake (SSC). It was postulated that the growth rate, reproduction performance and immunity level of communal sheep were significantly affected by insufficient nutrient supply from the rangelands. To investigate this, an analysis of herbaceous biomass yield and quality as well as the nutritional status of grazing sheep was conducted across all four (4) districts in Southern and Gaborone agricultural regions of Botswana. Additionally, it was presumed that higher levels of CM or SSC could have a negative impact on feed utilization, growth performance, carcass yield and quality as well as the overall health status of Tswana sheep lambs.

It was determined that feed supply and quality in the investigated communal rangelands were inadequate to sustain sheep production during dry seasons and this might have been exacerbated by their high bush encroachment (canopy cover at 70.63%). Most of small holder farmers utilized crop residues (67%) and lucerne/lablab hays (51%) in feeding their sheep and very few supplement their animals with oilseed meals. This study also evaluated the herbaceous yield and nutritional status of communal rangelands and found that the South East and Southern districts had significantly ($P<0.05$) lowest and highest feed supply respectively. Hence, sheep in the South East district had the statistically lowest live body weights and BCS in this work and may reflect their low total nutrients intake. Furthermore, the assessment of blood metabolites of sheep in the South

East district indicated intense mobilization of protein and energy reserves, probably due to extended feed scarcity and inadequate nutrients consumption during the dry seasons. Sheep from the South East district revealed highest (*P*<0.05) values of creatinine, BUN, glucose and cholesterol and these are mostly associated with severe hypoproteinamia and hypoglycaemia conditions. Again, the current study revealed that the nutritional and health status of grazing sheep was affected by their physiological status, with poor (*P*<0.05) BCS in lactating ewes. It must be noted that these low nutritional parameters in herbaceous forages and grazing sheep validate the importance of supplementing communal animals, especially with oilseed meals during the dry seasons.

Again, this study presumed that increasing levels of CM or SSC would negatively affect feed utilization, growth performance, carcass yield and quality and health status of this dominant sheep breed amongst local small-holder farmers. Thirty-six (36) castrated Tswana sheep weaners were randomly allocated nine (9) isonitrogenous (14% CP) diets in a completely randomized design (CRD) with four (4) animals as replicates. The SBM in experimental diets was substituted by CM or SCC at 0 (control), 25 (CM25/SSC25), 50 (CM50/SCC50), 75 (CM75/SCC75) and 100% DM (CM100/SCC100) inclusion levels and the best replacement rates of SBM were determined. Nutrient intakes and in-vivo digestibility of diets were affected (*P*<0.05) by inclusion rate of CM or SCC. Higher (*P*<0.05) intakes of dry matter (DM) and organic matter (OM) were observed in weaners that were fed CM75 and SCC75, while all diets had similar (p>0.05) crude protein digestibility. The results also showed that diets significantly (*P*<0.05) affected weight gains of lambs but did not affect (*P*>0.05) their final body weights, feed intakes, FCR and BCS. Even though CM and SCC influenced all investigated parameters similarly (*P*>0.05), CM produced numerically higher values of growth performance in Tswana sheep lambs. Regarding nitrogen utilization, it was found that diets affected (P<0.05) N-intake, weights of excreta (feces and urine) and daily output of fecal nitrogen while daily weights of urine nitrogen, nitrogen balance and retention were not affected. N-intake followed the pattern for total feed intake, DMI and CPI where it was higher (P<0.05) in sheep weaners fed diet SSC75 when compared to those fed diets SSC25 and SCC50 (32.25 vs 28.99 and 28.14 g/ day). Also, fecal output was inversely related to ADF, DMD and OMD levels of the investigated diets and it was significantly higher for sheep fed diets with high inclusions of CM, CM75 (1.02 kg) and CM100 (0.98 kg). Furthermore, all diets resulted in similar concentration levels of blood metabolites (except urea), normal levels of creatinine, total protein, Ca (except SSC100) and P and below normal levels of urea and albumin in Tswana lambs.

Once more, it was observed that all the diets had a significant influence (P<0.05) on various parameters including hot carcass weight (HCW), cold carcass mass (CCM), percentage of meat shrinkage, bone percentage, as well as the weights of ribeye, neck, rib-chop, leg, chump, loin, and rib-flank of the lambs. Animals fed control diet had significantly higher values of HCW and CDM than those that were fed diets SSC25 and SSC100. Furthermore, all CM and SSC diets, except SSC25, produced non-significant weights of rib-chop, leg, chump, loin and rib-cuts to control diet. The current findings also revealed that substituting SBM with CM or SSC affected the levels of drip loss, cooking loss and tenderness. Lamb meat with the highest drip loss percentage and lowest values of tenderness and highest fat and lowest moisture contents was produced by control and CM100 and SSC100 and SSC75 diets, respectively. Sensory evaluation scores indicated that replacing SBM with CM or SSC significantly affected all investigated sensory attributes of meat except taste and flavour, with higher (P<0.05) scores on tenderness, juiciness and overall impression in meat of lambs fed diet SCC75 than that of lambs fed control diet. From the results, it is concluded that CM or SSC has potential to partially or wholly replace SBM in grower sheep diets and feeding indigenous sheep improved cereal crop residues-based diets with CM or SCC has high chances of increasing mutton meat supply and consumption in hot and dry climates of Africa. A situation of high availability and affordability of animal protein has a high potential of reducing prevalence of undernourishment in the continent.

Keywords: Mutton, dietary strategies, canola meal, sunflower seed cake, growth performance, carcass traits, sensory attributes

DEDICATION

This work is dedicated to my late wife, Mrs Gaone Bonolo Legodimo, who gave me immense love, unwavering strength and zeal during each day of my research. I will forever love you my love, Gee. I also thank my son, Oratile and daughter, Katlo, for their inspiring smiles and jokes and constant prayers throughout this research work, especially during our sorrow time.

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CHAPTER 1 INTRODUCTION

1.1 Background

Tswana sheep contribute about 56% of sheep population in Botswana and they are mainly raised by small holder farmers (Statistics Botswana, 2019). This ecotype is classified as medium-sized and fat-tail sheep and is kept mainly for meat though not selected for any improved performances (Nsoso *et al*., 2004). These animals rely on rangelands as the main feed source (Aganga & Nsinamwa., 1997, Aganga *et al*., 2005) and have been observed to be resilient to harsh climatic conditions and parasites (Nsoso *et al*., 2004). Anecdotal evidence suggests that this breed is also highly prolific and has good mothering ability, important traits critical to increasing the lambing rates and sheep offtake per year in the face of the changing climatic conditions in Southern Africa and all over the world. Nevertheless, their body conditions tend to vary significantly with availability and quality of forage on rangelands. In most parts of Botswana, seasonality in the supply and quality of natural forages often coincide with physiological stages of sheep with high nutritional demands and thus reduce productivity. The lambing season normally occurs during cold and dry months (May/June), a period that usually results in high mortalities amongst newly born lambs due to severe cold weather, compromised health and inadequate nutrients supply (Aganga *et al*., 2005). These effects are further intensified by the low supplementation rates practiced by smallholder farmers in Botswana (Statistics Botswana, 2019).

Utilization of available low-cost feed resources could be one of the strategies to optimize the performance and profitability of Tswana sheep production. While cereal crop residues like maize stover have the potential to increase feed supply in Southern Africa (Bogale *et al*., 2008; Mthetho *et al*., 2015), their feeding value is low and need to be improved by inclusion of some good quality sources of protein and energy (Koralagama *et al*., 2008; Khalid *et al*., 2012; Abera *et al*., 2018). Low supplementation rates of Tswana sheep are likely to persist due to lack of capital to purchase the supplemental feeds and information on alternative strategies for improving the feed value of available feed resources specific for Tswana sheep. The major protein source in animal diets is soya bean meal which is becoming scarce and unaffordable due to competition between humans and animals for the same protein source as well as reduced production due to climate change. In Southern Africa, there has been an increase in the production of unconventional oilseeds meals with the potential to be protein sources for sheep. Oil seed meals are a by-product of oil extraction from seeds used mainly for culinary functions (Chitra, 2021). Amongst the oilseeds meals, canola meal (CM) and sunflower seed cake (SSC) are becoming increasingly available and affordable for use in animal diets (Nkosi *et al*., 2011; Sekali *et al*., 2016). They contain high levels of crude protein (CP) with canola meal containing up to 35-39% CP (Huhtanen *et al*., 2011; Canola Council of Canada., 2015) while sunflower seed cake contains 25.4 – 30% CP (Nkosi *et al*., 2011; Alves *et al*., 2016; Zagorakis *et al*., 2018).

The availability of canola and sunflower oil cakes in Southern Africa is likely to increase due to the favourable growth conditions these crops experience under the local climatic conditions (DAFF, 2018). Production of canola meal is also likely to be increased by a high demand for its oil, regarded as healthiest by consumers (Lin *et al*., 2013; DAFF, 2018). Since productivity of these oil crops appear to be sustainable, there is a need to increasingly integrate the remaining by-products of oil extraction for sustainable livestock production. Nevertheless, this requires assessing the nutritional values of such protein sources in Tswana sheep. Whereas evidence of the potential of canola as a protein source for improved sheep is readily available, adoption of feeding strategies using canola meal and SSC by local smallholder farmers who uses local sheep ecotypes for livestock production is likely to be low due to limited information on the influence of these meals on the performance of the Tswana sheep. It is therefore critical to evaluate the possible inclusion of such unconventional protein sources in animal diets for sustainable sheep production.

1.2 Problem Statement

The limited mutton production in Southern Africa is anticipated to contribute to a decline in meat self-sufficiency and potentially increase the prevalence of undernourishment in developing countries. In Botswana, information regarding the trends in sheep farming, particularly in the smallholder sector, is lacking. In addition, there is a lack of information on the inventory of feed resources for animals, making it difficult to profer nutritional strategies to improve animal production performance. Furthermore, information on the potential contribution of Tswana sheep to mutton production is limited. Moreover, while utilisation of improved diets can optimize growth performance of this native breed, their formulations are limited by lack of scientific information on nutritional requirements across all classes of sheep. Oilseed meals had been used to improve the performance of improved sheep breeds, but there is generally, scant data on the inclusion of sunflower seed cake and canola meal in Tswana sheep diets. There is also limited research on meat quality, cholesterol content and meat palatability of mutton from Tswana sheep in general. Therefore, the study was conducted to evaluate the characteristics of sheep farming under the local production system and to assess the feed resources and the nutritional and health status of sheep grazing in communal grazing rangelands and develop new and inexpensive diets appropriate for Tswana sheep lambs using Canola meal (CM) and sunflower oil cake (SOC) as main protein sources. The study also generated information on the growth performance, carcass characteristics meat quality and sensory properties of meat of Tswana lambs fed diets containing CM and SSC as protein supplements.

1.3 Justification

Raising Tswana sheep may have huge economic benefits to smallholder farmers in Southern Africa due to their low production costs. The indigenous Tswana sheep ecotype has adaptive attributes associated with surviving in arid conditions of Botswana, tolerance to most tropical diseases and can utilize poor quality feed resources (Nsoso et al., 2004). Its high disease tolerance that may result in low disease infections rate and reduced use of antibiotics. Nevertheless, information on the improvement of the feeding strategy of Tswana sheep is critical as it has the potential to optimise mutton production using indigenous sheep breeds. Evaluation of feeding strategies that involve use of unconventional protein sources such as canola and sunflower oil seed meals may enhance sustainable sheep production through development of new low-cost diets specific to Tswana sheep. The study therefore generated critical information on the general characteristics of sheep farming amongst communal farmers and assess the forage yield and quality and the effect of employment of feeding strartegies that utilize the oil seed meals in animal diets. Availability of such information may have the potential to stimulate increased use of the breed and adoption of inexpensive and highly efficient diets. These approaches will enable preservation and an increased use of indigenous breeds to enhance mutton production under the rising climatic temperatures associated with global warming.

1.4 Objectives

The major objective of the study was to evaluate the effects of inclusion of canola meal and sunflower oil cake as protein sources on growth performance, carcass characteristics and meat quality of Tswana lambs fed maize stover based diets.

The specific objectives of this study were:

- to determine sheep production practices amongst small-holder farmers in southeastern parts of Botswana
- to evaluate rangeland condition and nutritional status of sheep raised by communal farmers during the dry seasons in Botswana;
- to determine the nutrient intake and digestibility, growth performance and nitrogen utilization of Tswana lambs fed diets with different levels of canola meal or sunflower seed cake and
- to evaluate the effects of feeding diets with canola meal or sunflower seed cake on blood metabolites, carcass traits and meat quality of Tswana lambs.

1.5 Hypotheses

The study tested null hypotheses that:

- there is no data on sheep production systems and feed practices amongst smallholder farmers in southeastern part of Botswana;
- forage yield and quality have no significant influence on live weights, body condition scores and levels of blood metabolites of various categories of sheep raised on communal rangelands during dry seasons in Botswana;
- partial or whole substitution of SBM with CM or SSC as main protein sources in lamb diets has no significant effect on nutrient intake and digestibility, growth performance and nitrogen utilization and
- partial or whole substitution of SBM with CM or SSC as main protein sources in lamb diets has no significant effects in blood metabolites, carcass traits and meat quality of Tswana sheep lambs.

CHAPTER 2 LITERATURE REVIEW

2.1 Indigenous sheep breeds of Southern Africa and their adaptive features to arid conditions

There are approximately thirty-nine (39) million sheep in Southern Africa and 75% of these animals (about 29 million) are raised by smallholder farming farmers (Dzama, 2016). Most of the sheep breeds kept by the smallholder farmers are native breeds (Nyamushamba *et al*., 2017). Several authors (Kunene *et al*., 2007; Almeida *et al.*, 2011; Alves *et al.*, 2013; Molotsi *et al*., 2020) identified Sabi (Zimbabwe), Damara (Namibia), Landium (Mozambique), Swazi (Iswatini), Namaqua Afrikaner/Ronderib Afrikaner/Pedi/Nguni (South Africa), Zambian Fat-tailed (Zambia) and Tswana (Botswana) as the indigenous sheep breeds of Southern Africa. These authors indicated that these breeds are classified as hairy and fat-tailed; hence, their resilience to harsh climatic conditions prevailing in the semi-arid environment as well as parasites and diseases. The fat deposits in the tail are often metabolized slowly to provide steady energy supply during extended periods of undernutrition (Assan *et al*., 2002; Atti *et al*., 2004) and reduces seasonal weight loss by the sheep (Alves *et al*., 2013). These adaptive attributes give indigenous breeds a competitive edge over exotic temperate breeds in improving food security in arid and semi-arid condition and under the current global warming challenges (Rust & Rust, 2013; Dzama, 2016; Nyamushamba *et al*., 2017). However, the potential of these native sheep is often overlooked by most researchers and commercial farmers, as evidenced by their low participation in scientific investigations and mutton markets regionally. Despite this, these native breeds continue to play a paramount role in socio-economic lives of resource poor masses of Southern Africa as a source of investment, meat, milk, income, skins and manure (Rege, 1998; Kunene *et al*., 2007; Almeida *et al*., 2011; Dzama, 2016).

2.2 The role of Tswana Sheep to smallholder farmers in Botswana

This breed is mainly kept for mutton production (Aganga & Fabi, 2007), with yearling castrates as the most marketed by smallholder farmers. On average a mature Tswana castrate weighs 39 kg (Aganga & Fabi, 2007) and it is likely to yield a carcass weight of 19.5 kg when using dressing percentage (50%) suggested by Wariss (2000). While carcass weight is mostly used in selling meat animals after slaughter, in Botswana sheep are mostly sold by estimating their live weight “by eye” (Sebolai *et al.*, 2012; Temoso *et al.*, 2017). This strategy tends to be convenient for most rural farmers as it cuts transport costs; it also provides consumers with opportunity to harvest most offals (organ meats) for most traditional dishes (Van Heerden *et al.*, 2014). Increase in demand of these traditional cuisines in urban and peri-urban areas in Botswana shows that amount of meat from skeletal muscles (dressing percentage) cannot be regarded as the only marketing tool or potential source of animal protein. Since this breed is mostly kept by resource-poor farmers who own few cattle, it is also conveniently used in marriage feasts, lobola, funerals and spiritual rituals. Also, its multi-coloured characteristic makes it a convenient breed for traditional healers when looking for sheep to sacrifice. Health and colour, not weight, are important factors when selecting a sacrifice animal for rituals (Mokgobi, 2014).

2.3 Sheep population trends, productivity indicators and government programmes for communal farmers

2.3.1 Sheep production amongst communal farmers in Botswana

According to annual agricultural survey reports (Statistics Botswana, 2003 – 2019), the communal sheep population in the country decreased by 34.4% and 11.7% from year 1999 to 2017 respectively (Figure 2.1). The reports also showed that the number of sheep farmers in communal farming decreased by more than 50% from 1999 to 2017. This decline of sheep population may be attributed to various factors like loss of interest in sheep farming, poor market prices, diseases, poor nutrition as well as concurrent droughts. According to Statistics Botswana (2017), the country had fourteen (14) drought declarations during the same period.

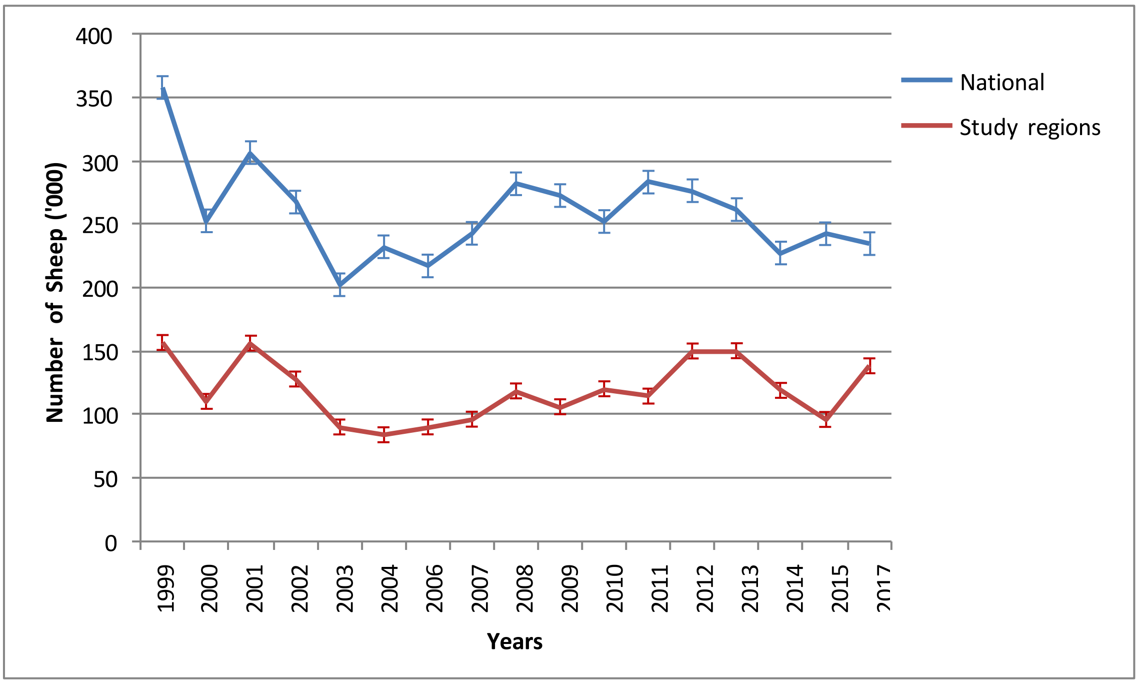

Figure 2. 1 Trend of sheep population in Gaborone and Southern regions from 1999 to 2017
Sources: Statistics Botswana 2003 - 2019. Annual Agricultural Reports

Births rate decreased by 8.3% from year 1999 to year 2017, while deaths rate declined sharply by 14.8% from year 1999 to year 2008 and thereafter rose slowly by 2.7% in the year 2017 (Figure 2.2). The same figure also showed that the average offtake and home slaughter rates from communal farmers in Botswana were 5.7% and 3.4% respectively.

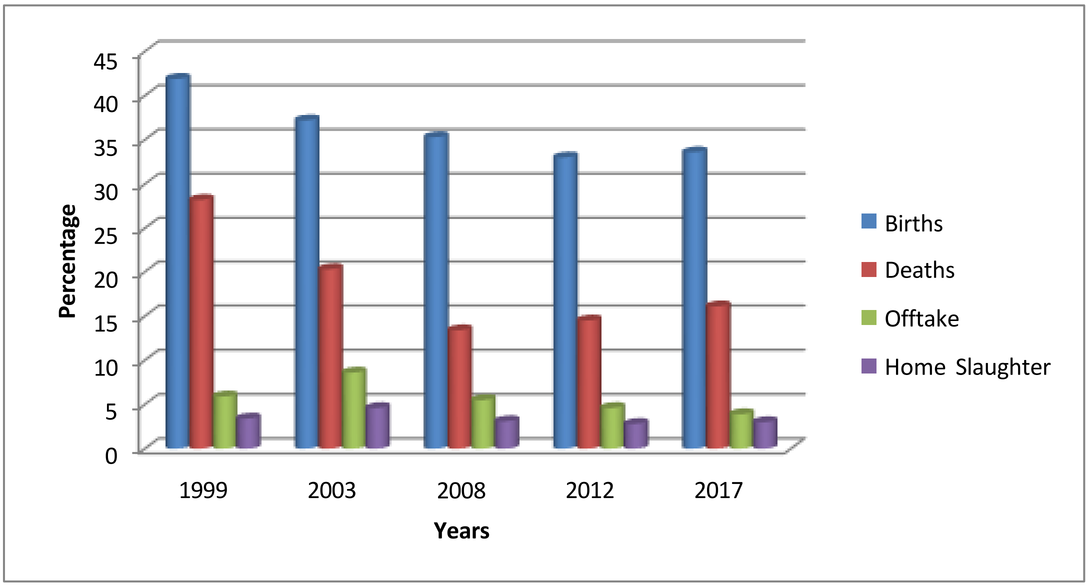

Figure 2. 2 Productivity indicators of national sheep in communal farming

Sources: Statistics Botswana 2003 - 2019. Annual Agricultural Reports

2.3.2 Population trends of sheep breeds kept by communal farmers in southeastern regions of Botswana

Generally, a positive relationship exists between the national sheep population and the number of Tswana sheep, as indicated by high percentage of Tswana sheep in national sheep census (Figure 2.3). The national population of Tswana sheep breed stood at 131, 881 (about 56% of the total sheep) in year 2017 (Statistics Botswana, 2019), a significant decrease when compared to 189, 567 (78% of national population) in year 2008 (Statistics Botswana, 2012). Figure 2.3 also shows that the number of this breed in Southern and Gaborone regions rose by 9.68% from 2004 to 2017 and declined by 29.1% from 2013 to 2017. This downward trend may be attributed to many factors associated with poor nutrition, diseases and increased cross breeding. Between 2004 and 2017, the practice of crossbreeding indigenous sheep with improved breeds in the two investigated regions experienced a notable rise of 81.4%. However, this trend raises concerns about the potential loss of valuable traits inherent in Tswana sheep like hardiness, with resistance against tick-borne diseases and high fertility (Nsoso *et al*., 2004; Almeida *et al*., 2011; Dzama, 2016).

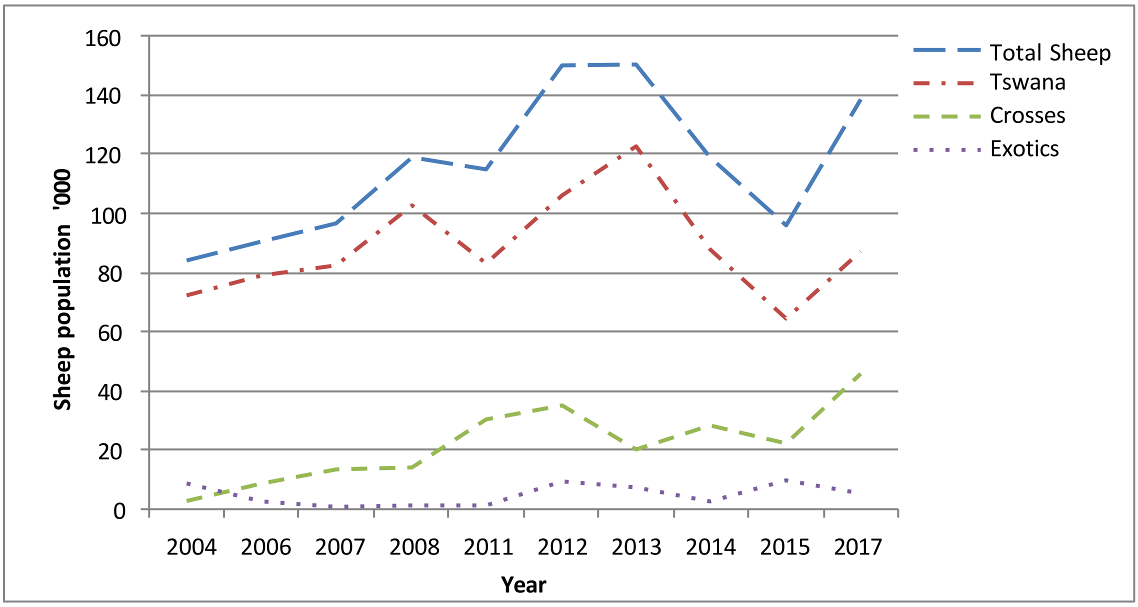

Figure 2. 3 Trends of sheep breeds population in Southern and Gaborone regions in Botswana from year 2004 – 2017

Source: Sources: Statistics Botswana 2003 - 2019. Annual Agricultural Reports

2.3.3 Government programmes for communal sheep farmers.

Despite many challenges that have affected sheep production locally, government has provided various financial and technical assistances to support new and existing small stock businesses in both commercial and communal farms through Financial Assistance Policy (FAP) that ceased in 2001 and Citizen Entrepreneurial Development Agency (CEDA) that started in 2001 (CEDA Guidelines, 2008). There were other assistances that targeted specific groups of farmers like youth such as Youth Development Fund (YDF) (Youth Development Fund Guidelines, 2017) and CEDA Young Farmers Fund (CEDA Guidelines, 2008; Williams and Hovorka, 2013), resource poor farmers like Livestock Management and Infrastructure

Development (LIMID) (LIMID Guidelines, 2007) and Poverty Eradication Programme (Poverty Eradication Guidelines, Implementation and Packages, 2012) and the resource poor areas (Special Integrated Support Programme for Arable Agriculture Development - Special ISPAAD) (Ministry of Agriculture, 2014). LIMID program started in 2007 after merging SLOCA (Support to Livestock Owners in Communal Areas) and LWDP (Livestock Water Development Program) in 2002 and aims at improving food security and erad icating poverty (Moreki *et al*., 2010). Again, in 2007 CEDA Young Farmers Fund programme was also launched, while Poverty Eradication Programme and Special ISPAAD were introduced in years 2009 and 2014 respectively and all these programmes were still utilized by communal sheep farmers by year 2017.

2.4. Major challenges to sheep production by communal farmers in Botswana

2.4.1 Low availability of forage and poor nutrition

Natural rangelands remain the main source of feed for livestock in Botswana (Aganga *et al*., 2005) and availability and quality of rangelands feed resources vary with season and rainfall amount (Aganga *et al*., 2005), soil properties and topography (Nsinamwa *et al*., 2005; Pule *et al*., 2018). The country is dominated by poor soils (sandveld) and long dry seasons resulting in poor quality natural forages and ultimately inadequate nutrient supply for optimum sheep production. This situation is further worsened by poor management practices among farmers, including a low rate of livestock supplementation (Botswana Statistics, 2019) and high stocking rates (Makhabu *et al*., 2019). Consequently, this leads to high nutritional stress in sheep during dry periods as they must travel long distances in search of better-quality forage. Added to that, Malope and Batisani (2008) and Makhabu *et al.* (2019) indicated that the current tribal land grazing policies continue to increase grazing pressure in communal areas during dry seasons by giving ranchers dual rights to graze their animals in both ranches and communal grazing area and also fail to regulate the number of animals, according to the carrying capacity of the grazing area. Also, overgrazing around watering points has led to bush encroachment around such areas, especially of acacia species (Moleele & Perkins, 1998). Such species have poor forage value to grazers like sheep and cattle and their abundance in rangelands may lead to low forage intake and poor productivity levels amongst these animals.

2.4.2 Animal diseases and parasites

Locally, sheep production in communal areas is mostly affected by helminthiosis, coccidiosis, tick-borne and bacterial diseases as well as external parasites (Segwagwe & Ramabu, 1999; Sharma & Busang 2013; Bethelsson *et al*., 2020). Amongst external parasites, several Sacroptic mange outbreaks in sheep had been reported in last ten (10) years in Botswana. To make matters worse, inadequate disease management among farmers along with limited veterinary services at local level (Gaolebogwe, 1999; Moreki *et al*., 2010) allowed disease to spread in small livestock owned by economically disadvantaged. Consequently, this has led to diminished reproduction and production indices. However, there are several methods that could be used strategically by smallholder farmers to reduce diseases and parasites in small ruminants like vaccinations (Feenstra & Van Rijn, 2017), use of drugs (Gnosh *et al*., 2007) and provision of adequate nutrition (Fleming *et al*., 2006; Paul & Dey, 2015).

2.5 Maize stover as a ruminant feed and its limitations

2.5.1 Production and potential use of maize stover as feed in Botswana

In Botswana, traditional arable sector contributed 13, 911 metric tons of maize grains in year 2017 (Statistics Botswana, 2019) and this had potential to produce between 27,822 to 69,555 metric tons of maize stover if one uses approaches used by Syomiti *et al.* (2011) and Streeter *et al.* (1993) to estimate the potential yield of cereal stover. While this amount of maize stover could sustain its sheep population in year 2017 for one month when fed alone, there was a huge potential supply of maize stover from the SADC member states (excluding Madagascar) that produced 47 million metric tons of cereal grain (SADC, 2017). The report also indicated that maize is the dominant cereal crop in the region, with South Africa (18.16 million MT) as the leading cereal grain producer followed by Tanzania (9.39 million MT), Zambia (3.89 million MT) and Malawi (3.68 million MT).

2.5.2 Factors limiting maize stover as a sole feed to ruminant animal

Various studies indicated that maize stover contains high amounts of neutral detergent fibre (NDF), acid detergent fibre (ADF), lignin plus low levels of crude protein (CP) content (Table 2.1). However, according to some reports (Akbar *et al*., 2002; Ouda & Nsahlai, 2007; Sun *et al*., 2019), variances exist in nutritive values of the maize stover attributed to the different maize varieties, climatic conditions, agronomy factors, the exposure time in the field and activity of protein degrading micro-organisms. While lignin provides structural support and chemical protection against pathogen invasion during plant growth (Xie *et al*, 2018), it has become one of the major limiting factors in utilization of crop residues in animal feeding. Lignin binds carbohydrates and proteins in tightly cross-linked lignocellulosic structure polymerized on surface of cell walls (Frei, 2013; Xie *et al*., 2018) and makes them highly resistant to digestion by enzymes and rumen microbes (Van Soest *et al*., 1991).

Due to the low-quality nutritional characteristics, maize stover has low digestibility (Yang *et al*., 2009) and metabolisable energy (Mc Donald *et al*., 1995). Therefore, ruminants fed such poorly digestible forage like maize stover may spend longer time re-chewing it, a scenario that would deprive them opportunity to feed enough to meet nutrients requirement for maintenance and production (Moyo *et al*., 2019) resulting in poor productivity. In addition to low feed intake, the consumption of maize stover often lead to high rumen retention time and low microbial activity in reticulo-rumen due to inadequate nitrogen and fermentable energy supply to enhance multiplication of rumen microbes (Mgheni *et al*., 2001; Abera *et al*., 2018). Other sources (Van Soest, 1994; Sampaio *et al*., 2009; Sampaio *et al*., 2010) indicated that rumen optimal microbial growth and improved fibrolytic activity require a minimum crude protein 7% CP and ruminal ammonia nitrogen concentration of 3.6 - 7.2 mmol/L. Failure to meet these requirements will result in inadequate supply of microbial protein and volatile fatty acids for utilization by ruminants and thus poor weight gains (Stern *et al*., 2006). Low energy supply as result of low production of volatile fatty acids (Henderson *et al*., 2015; Mamuad *et al*., 2019) in ruminants fed sole maize stover diets will be exacerbated by high energy loss through increased methane production (Johnson & Johnson, 2006).

Table 2.1 Chemical composition of maize stover (%DM) and metabolisable energy concentration (MJ/kg DM) as reported by different sources

DM	CP	CF	NDF	ADF	ADL	Ash	Ca	P	ME	SOURCES
46	8.34		73.30	69.10						Wambui *et al.* (2006)
54	5.4	28.3				9.0	0.28	0.12		Macala *et al.* (1995)
	6.63		68.61	42.10	5.99					Legodimo (2013)
93.25	4.71	18.30				0.42				Tona *et al.* (2015)
	3.62		72.46	44.05		4.95				Ouda and Nsahlai (2007)
90.8	5.9		85.5	54.7	4.1					Abera *et al.* (2018)
93.38	4.05		71.93	41.36	6.26		0.40	0.05		Li *et al.* (2014)
93.3	3.6		86.2	45.8	4.6				6.3	Lopez *et al.* (2005)
92.3	6.00		83.98	59.11			0.23	2.62		Chakeredza *et al.* (2001)
93.9	3.8		73.8	49.3	9.4	8.5				Koralagama *et al.* (2008)
46	8.34		73.30	69.10		7.75				Wambui *et al.* (2006)
93	9.6		71.8	61.48	11.8					Moyo *et al.* (2019)
92.0	4.8		55.9	25.9	12.2	9.4				Montanez-Valdez *et al.* (2015)
	6.0								9	Mc Donald *et al.* (1995)
90.4	3.25		74.6	47.5		6.13	0.29	0.27		Faftine and Zanetti (2010)
93.4	3.1		80.1	53.1	8.3	6.9	2.5	1.4		Tolera and Sundstol (2000)

2.6 Main methods for improving nutritive value of maize stover based diets

2.6.1 Physical, chemical and biological methods

Due to poor quality attributes of maize stover, it is widely advised that maize stover needs to be processed first before feeding to ruminants. Processing of maize stover can be achieved through physical, chemical and biological treatment as well as use of genetic engineering in the modification of lignification (Wanapat *et al*., 1996). Reduction of feed particle size of maize stover through chopping and grinding reduces feed wastage, increases feed intake and rate of passage as well as surface area for microbial attachment in the rumen (Smith, 1989; Tafaj *et al*., 2001). This may also reduce feeding costs and improve digestibility of maize stover fed to ruminants. However, it is recommended to avoid excessively fine grinding of the feed, as this practice can lead to a faster rate of passage and reduced digestibility (Zewdie, 2019). This is primarily due to the insufficient time available for microbial attachment in the reticulorumen. Despite the potential of physical treatments, other researchers have a conflicting view regarding these treatments. These methods are believed to have poor quality/cost ratio in improving the nutritive value of forages like crop residues (Wanapat *et al*., 1996). This may result in low farming profits amongst most smallholders who solely rely on these methods to improve their crop residues.

When investigating the effects of chemical treatments on improving the quality of poor roughages, Wanapat *et al*. (1996) and Ali *et al*. (2012) indicated that urea and ammonia are the most common methods used. These methods hydrolyse lignin-polysaccharides' ester bonds and softens the feed particles and thus improves feed palatability and feed intake of maize stover fed sheep (Ali *et al*., 2012) as well as increase nitrogen (NPN) supply for microbial multiplication and improve fibre digestion in the rumen. As a result, this leads to an augmented availability of microbial protein and volatile fatty acids forsheep consuming such treated stover and hence, improves their weight gains (Said *et al*., 1982; Stern *et al*., 2006; Abera *et al*., 2018). On the contrary, Wanapat *et al*. (1996) pointed out that there are some challenges regarding treating roughages with chemicals including the high labour costs, leaching towards bottom layers of stover stacks, insufficient diffusion of ammonia within treated stover, environment pollution and urea/ammonia toxicity. The authors also noted that to achieve optimum ureolysis in treated roughages, the best temperatures should be within 30 - 60 ^{0}C. These temperatures may be challenging during the winter seasons amongst farmers in the arid areas like Kalahari Desert which usually experience temperature below 5^{0}C.

Concerning biological treatment methods, the incorporation of microbial cells, microbial extracts, or microbial enzymes into feed is a common strategy aimed at enhancing feed efficiency and increasing the availability of nutrients that are predominantly enclosed within insoluble structures (Salem *et al*., 2011; Breanna *et al*., 2017). In addition, Breanna *et al*. (2017) pointed that promoting the release of carbohydrates supports microflora and suppresses pathogenic microbes (Breanna *et al*., 2017). Commonly used dietary exogenous enzymes are proteolytic, amylolytic and fibrolytic (Salem *et al*., 2011) as well as the phytase (Buendia *et al*., 2010). Addition of dietary exogenous enzymes in highly fibrous diets was shown to improve palatability, digestion and nutritive value in both non-ruminant (Alagawany *et al*., 2018) and ruminant (Buendia *et al*., 2010) animals. Enzymes were also shown to significantly improve growth rates and carcass weights in broiler chickens (Disetlhe *et al*., 2017), growth performance of pigs (Nkosi *et al*., 2020) and small ruminants (Salem *et al*., 2011). However, use of exogenous enzymes is more used in non-ruminants than ruminant feeding (Breanna *et al*., 2017).

2.6.2 Energy Concentrates and their effects on ruminant performance

Dietary energy for animals often comes from simple sugars, starches, cellulose, hemicellulose and fructans of grains and forages (Hosseini *et al*., 2008). Starch is the dominant energy source in ruminant diets (Ortega & Mendoza, 2003) and plays a major role in modulating ruminal fermentation and promoting utilization of nitrogen sources in the rumen (Gomez *et al*., 2016). Starch is a polysaccharide of plants (mainly alpha-glucans) made of amylose (a linear polymer containing 99% α-1,4 linkages) and amylopectin (a branched polymer containing 95% α-1,4 linkages and 5% α-1,6 linkages) molecules (Parker & Ring, 2001; Stevnebo *et al*., 2006). According to Santana and Meireless (2014), the arrangement of amylose and amylopectin in starch granules and starch granules properties differ between its main sources, cereal grains (wheat, oats, barley, maize and sorghum) and tubers or roots (cassava and potatoes). These authors also emphasized that this difference has a significant impact on the role of various starch sources in feed formulations. In addition, Gomez *et al*. (2016) and Wang *et al*. (2016) pointed that feeding diets dense in highly fermentable starch (cereal grains and tubers/roots) result in rapid accumulation of volatile fatty acids, subsequently inducing acidic conditions in the rumen. The investigations further indicate that acidic rumen environment lowers population of cellulolytic bacteria, increases passage rate and decreases fibre digestibility. Other good sources of energy for ruminant nutrition include agro-industrial by-product like molasses (Preston, 1988; Salvador *et al*., 2016; Mordenti *et al*., 2021), brans (Mahabile *et al*., 2000; Dhakad *et al*., 2002), distiller grains and citrus pulp (Romero *et al*., 2014) as well as fats and oil (Church, 1991; Mc Donald *et al*., 1995).

Supplementing ruminants with high-starch (energy concentrate) increases population of rumen microbes (mainly bacteria, fungi and protozoa) and fermentation and stimulates high production of short chain fatty acids (acetic, propionic and butyric) and microbial protein (Van

Soest, 1994). In addition, Gomez *et al*. (2016) reported that improving the efficiency of reticulo-rumen result in increased digestibility, reduced retention time in the rumen and increased feed intake. Higher feed intake was also reported by Wang *et al*. (2020) in diets containing ME of 2.49 Mca/kg than that with 2.19 Mcal/kg in Hu lambs. However, with dietary energy density regulating feed intake in ruminants, reduced feed intake was observed in lamb diets >2.49 Mcal/kg ME (Wang *et al*., 2020) and 3.05 Mcal/kg ME (Rios-Rincon *et al*., 2014). On the contrary, higher average daily gains were observed by Hosseini *et al*. (2008) in Bahmei lambs fed diets containing 2.60 Mcal/kg than those fed 2.34 and 2.47 Mcal/kg diets.

High dietary energy density also improved average daily gain, carcass weight and dressing percentage in Omani growing lambs (Mahgoub *et al*., 2000), kidney-pelvic percentage in Pelibeuy cross lambs (Rios-Rincon *et al*., 2014), carcass performance in Bahmei lambs (Hosseini *et al*. (2008) and carcass traits in grazing Suffolk lambs (Britez *et al*., 2020). According to Guo *et al*. (2021), these performance improvements are influenced by increased proportion of propionate and valerate. Furthermore, Hosseini et al. (2008) highlighted that the supplementation of sheep with energy concentrates enhances their reproductive performance, resulting in increased estrus activity, ovulation rates, fertilization rates, and the survival of ova. Additionally, it supports the maintenance of resulting embryos to term, leading to the birth of viable lambs.

2.6.3 Protein Concentrates and their effects on ruminant performance

Normally protein concentrates are classified as per their sources, animal protein, protein-rich plants and single-cell protein (microbial biomasses), according to Mc Donald *et al*. (1995). Furthermore, Stein *et al*. (2008) stated that dietary proteins are mainly made of four (4) types of proteins, with different degradability; albumins and globulins (highly degradable) and prolamines and glutelins (slowly degradable). Use of processed animal protein sources like carcass and blood meals in ruminant feeding had been prohibited due to their association with Mad Cow Disease (Imran & Mahmood, 2011; National Grain and Feed Association, 2011). This has left plant protein sources (oilseed cake and meals, leguminous grains and forages) as well as microbial masses (microalgae, yeasts and bacteria) as main providers of high-quality protein in farm animal feeding around the world (Parisi *et al*., 2020). Investigations by various researchers (Khalid *et al*., 2011, Sekali *et al*., 2016; Seid & Animut, 2018; Obeidat *et al*., 2020) have shown that oilseed meals or cakes (soybean, canola, flaxseed, peanut, safflower, sunflower and cottonseed), leguminous seeds (beans, peas and lupins) and forage legumes (lucerne, cowpeas, groundnut, lablab, *Leucaena leucocephala*) improved the quality of poor-quality forage based diets. They improved feed intake, daily weight gains and carcass quality of sheep fed such diets. Oilseed meals contain high quality protein, Mc Donald *et al*. (1995) noted that about 95% of protein in oilseed meals is true-protein with high apparent digestibility (0.75 - 0.90). However, large differences in nutritional quality in a particular oilseed meal or cake are attributed to different methods employed during extraction of oil from such grains (Ramirez-Bribiesca *et al*., 2018). In addition, oilseed meals contain considerable amount of oil that act as energy source (Mc Donald *et al*., 1995) and reduce methane production in ruminants. It is reported that oil directly inhibit ruminal methanogens as well as reduces excess hydrogen available for methane synthesis (Klim *et al*., 2020).

Amongst these oilseed meals, soybean meal (SBM) is reported to be the most utilized protein concentrate in animal finishing diets due its high protein content (44 - 48%) and low amount of fibre (Sekali *et al*., 2020). However, utilization of SBM in farm animals is limited by its high demand in food production to support the ever-increasing human population and its high-cost production (Ruzic-Muslic *et al*., 2014). Finding ways of reducing costs associated with utilizing SBM in animal feeding had been suggested and in their studies (Sekali *et al*., 2016; Zagorakis *et al*., 2018; El-Nomeary *et al*., 2021) other oilseed meals that are cheap showed their potential to replace SBM partially or completely in ruminant feeding.

2.7 Oilseed meals production, nutritional value and growth performance of small stock

2.7.1 The potential of sunflower seed cake and canola meal as a feed resource for livestock in Southern Africa

Botswana had been producing less than 16 metric tonnes of sunflower grains annually for the past years and does not produce canola (Botswana Statistics, 2019). Additionally, the country has a limited number of cooking oil producers, resulting in it being a net importer of sunflower products, including sunflower seed cake. Most of imported sunflower seed cake comes from South Africa, where sunflower is reported to be the third largest grain crop after maize and wheat and second largest oilseed crop with production over 900 000 tonnes (tons) after soya bean (1.3 million tonnes) in year 2017 (DAFF, 2017). High utilization of sunflower seed cake in dairy feeds and demand of oil in human diets will always drive production of sunflower in South Africa (Boshoff, 2008). DAFF (2018) also noted that even though canola is a distant third largest (96 600 tonnes) grown oil crop in South Africa and its local production is increasing at faster rate due to growing demand for its oil. Canola oil is regarded as the healthiest edible oil with very low saturated fat (7%) and high amount (93%) unsaturated fats, levels that may protect the consumers against cardiovascular diseases like heart attacks and strokes (Lin *et al*., 2013). An increase of middle class and health-conscious consumers is more likely to stimulate high production of canola oil and thus high availability of canola meal. Increase in demand for wheat and wheat products as well as milk and milk products have a potential to increase the production of canola. Growing canola before wheat in crop rotation is reported to increase wheat yields by a maximum of 25% in Western Province in South Africa, while including canola meal in dairy rations at 20% increases milk production in dairy cows by 1 litre per day (DAFF, 2018). These approaches will result in high production of canola meal that may be used in animal feeding in South Africa and surrounding countries.

2.7.2 Nutritional value of soybean meal, sunflower seed cake and canola meal

2.7.2.1 Chemical composition of soybean meal

Soybean meal is the main protein source in animal diets globally due to its high palatability, high CP content (full fat meal - 38 to 42% CP, mechanically extracted - 41 to 44% CP while solvent extracted meal - 44 - 50% CP) and large amount of essential amino acids (Jurgens *et al*., 1997; Yin *et al*., 2014; Alves *et al*., 2016; Zagorakis *et al*., 2018). Soya bean meal is rich in lysine but has limited amounts of sulphur amino acids (methionine and cysteine). These sulphur-containing amino acids together with lysine may limit growth, milk and wool production if they are not adequately provided in diets (Nezamidoust *et al*., 2014). SBM had been found to be highly digestible (Stein *et al*., 2008) compared to other oilseed meal. On comparison, full fat SBM contain 18.25% crude fat, 5.54% crude fibre and a total energy content of 3809 Kcal/kg while solvent extracted soymeal has 1.23% crude fat, 3.95% crude fibre and total energy level of 2934 Kcal/kg (Harlioglu *et al*., 2021). Jurgens *et al*. (1997) found that SBM contains 71% to 80% Total Digestible Nutrients (TDN) low in calcium (0.30%), fair in phosphorus (0.65%).

2.7.2.2 Chemical composition of sunflower seed cake

Sunflower seed cake is good protein source with CP content ranging from 17.4 – 36.7% CP, depending on the extraction method applied, with cakes from fat dehulled seeds and whole seeds having the highest and lowest levels of CP respectively (Trombetta *et al*., 2007). Previous studies indicated that sunflower seed cake contains lower lysine (3.6% CP) and higher sulphated amino acids (methionine 2.3% CP and cysteine 1.7% CP) compared to SBM (lysine 6.1% CP, methionine 1.4% CP and cysteine 1.5% CP). Due to its high methionine content, diets containing sunflower seed cake as the main protein source are expected to improve lamb growth performance (Nkosi *et al*., 2011). The method of oil extraction and dehulling also influences the level of fat content in the cake, with that from whole seeds having the highest fat and crude fibre percentages. Furthermore, environmental conditions and varieties do influence the level of crude fat and crude fibre contents of cake. In Greece, Kargopoulos *et al*. (2017) found that SFC contains crude fat and crude fibre contents at 22.0% and 23.8% respectively. In other parts of the world, Moura *et al*. (2015) in Brazil and Nkosi *et al*. (2011) in South Africa found that the cake contains (20.7% vs 30.8% crude fat) and (15.7% vs 30.8% crude fibre) respectively. High fibre and low lysine contents of sunflower seed cake had been reported to be the major limiting factor of this protein source in poultry diets by Vilamide and San Juan (1999). Conversely, it was reported that the cake has high rumen degradability of protein (>90%) by Oliviera *et al*. (2007) and thus possess the greatest potential in ruminant rations (Nkosi *et al*., 2011). The latter also indicated that sunflower seed cake has a metabolisable energy content of 15.7 MJ/kg DM.

The high fibre content in sunflower seed cake had been identified as the only limiting factor in diets containing the high level of cake. Feeding diets containing high levels of SFC resulted in low feed intake and poor growth rates in poultry fed diets (Villamide & San Juan, 1999), pigs (Carellos *et al*., 2004) and growing lambs fed (Nkosi *et al*., 2011). Also, it was found out by Plameiri *et al*. (2012) that carcass traits of crossbred Boer goats were not affected by replacing

100% SBM (at 15.40% inclusion rate) by 100% sunflower seed cake (at inclusion rate of 23.65%).

2.7.2.3 Chemical composition of Canola meal

Canola meal is a by-product of oil extraction from canola seeds and the name canola refers to genetically developed cultivars of rapeseed (Brassica napus and Brassica campestris/napa) to produce oil portion with low erucic acid (<2%) and meal portion with glucosinolates (<30 µmol/g) (Bell, 1993; Hubtanen *et al.*, 2011; Canola Meal Feeding Guide, 2015). Hubtanen *et al*. (2011) also referred to these cultivars as double-zero or double-low oilseed rape as double and indicated that development of canola crop has hugely increased production of edible canola oil and canola meal for human consumption and animal feed respectively. Just like other oilseed meals, the quality of canola meal is related to the type of oil extraction process used (solvent-extraction or expeller), reported by authors (Spragg, 2013; Wickramasuriya *et al*., 2015). It is reported by Khajali and Slomiski (2012) that canola meal contains protein, carbohydrates (simple sugars, sucrose, oligosaccharides, starch), dietary fibre (non-starch polysaccharides, lignin with associated polyphenols, glycoproteins), fat and ash. Canola contains high CP content (35 - 41.1%) (He *et al*., 2013; Maison, 2013; Wickramasuriya *et al*., 2015; Mnisi & Mlambo, 2018). Most reviewed literature have reported that canola meal contains high quality amino acids profile for animal feeding, with high levels of sulfur containing amino acids (Methionine and Cystine) and limited in lysine content. Processing methods tend to affect the quality of protein and availability of amino acids, for instance excessive heating leads to Maillard/browning reactions and reduction of lysine content and this may greatly affect use of canola meal in monogastric feeding (Bell, 1993). Nonetheless, in their review Khajali and Slomiski (2012) found that canola meal contains 2.00% lysine, 0.74% methionine and 0.85% cystine. They also noted that the meal contains ether extract (3.6%), ash

(6.8%), crude fibre (11.6%) and low metabolisable energy compared to SBM (2,000 vs 2,230 Kcal/kg). Fairly high contents of calcium (0.65%) and phosphorus (0.99%) had been reported by Canola Meal Feeding Guide (2015).

Canola meal is highly degraded in the rumen, resulting in high wastage dietary protein, excess ammonia and high excretion of urea (Bell, 1993) and has fairly low rumen escape protein (43.5%) (Canola Meal Feeding Guide, 2015). When investigating the effects of different protein sources on performance of growing lambs, Khalid *et al*. (2011) found higher DM and CP intake, DM, CP and NDF digestibility, nitrogen retention, total body weight and blood glucose concentration in animals fed canola meal diets than those fed diets containing either cotton seed meal, sunflower meal or corn gluten meal as main protein source. Conversely, Sekali *et al*. (2016) found that replacing SBM completely with CM (at 25.3% inclusion rate) in diets fed Mutton Merino lambs produced similar hot carcass weights but different cold carcass weights.

2.7.3 Yield of volatile fatty acids and methane emissions from ruminants fed sunflower seed cake and canola meal-based diets

Good digestibility of sunflower seed cake and canola meal observed by Moura *et al*. (2015) and Khalid *et al*. (2011) respectively may be a result of high availability of dietary nitrogen to enhance optimal microbial activity in rumen. High microbial synthesis in the rumen ensures efficient digestion of fibrous feeds and thus high volatile fatty (VFAs) and low methane production. The rate of methane (CH_4) production is believed to represents the amount of energy lost; with Johnson and Johnson (1995) estimating an energy loss that follows between 2-12% of gross energy (GE) in ruminants. Toprak (2015) indicated that the best and easiest way of reducing methane in ruminants is to feed those diets with addition of fat or supplementing with oilseeds meals. These feeding practices inhibit methanogens and protozoa in the rumen (Hook *et al*., 2010). In addition, Beauchemin and McGinn (2006) noted that the type of oils in the diets influences rate of enteric methane production and indicated that feedstuffs that are dense in long-chain fatty acids like sunflower and canola can improve efficiency of GE by 22% in ruminants fed diets rich in roughage. Ramirez-Bribiesca *et al*. (2018) found that canola meal extracted through cold pressing contained high oil content (13.99%), produced high propionate and less methane gas when compared to solvent-extracted.

2.7.4 Feed Intake and Growth performance of lambs fed sunflower seed cake and canola meal-based diets

The performance of Merino sheep fed different levels of sunflower meal was observed to be similar to that of those fed soya bean meal (Nkosi *et al*., 2011). Furthermore, Moura *et al*. (2015) found no differences in DM intake of sheep fed diets containing different substitution levels (0, 25, 50, 75, 100%) of SBM for sunflower seed cake. Irshaid *et al*. (2003) also noted the absence of substantial disparities in average feed intake, average daily gain (ADG), final body weight, and feed conversion rate (FCR) among Awassi lambs that were fed diets comprising varying substitution levels (0%, 50%, 100%) of soybean meal (SBM) instead of sunflower meal.. These authors also pointed that similar feed intake amongst rations may suggest similar or even better palatability of sunflower meal than SBM. On the other hand, statistically similar feed intake and average daily gains were observed in Mutton Merino sheep fed diets containing canola meal and those fed diets with soya bean meal, at equal inclusion rates (Sekali *et al*., 2016). A similar trend in animal performance was also observed by Sekali *et al*. (2020) when they investigated the influence of expeller canola meal in Meatmaster lambs, concluded that heat treatment has no effect on growth rate of sheep and recommended that SBM can be completely substituted with canola meal, either heat-treated or untreated. However, diets containing 33% canola meal were found to have significantly low feed intake and no negative effects on the growth performance in Atabay lambs (Rezaeipar *et al*., 2016). The study also observed that increase in inclusion rate of canola meal in sheep diets did not affect feed efficiency ($P<0.01$).

2.8 Methods of assessing Nutritional and Health status of live sheep

2.8.1 Live body weights

Body weight is widely used to estimate the energy status of sheep at any time (Brown *et al*., 2015) and this means inadequate energy intake will greatly suppress the growth rate of small stock (Mahgoud *et al*., 2000). Hence, the body weight of sheep raised on rangelands indicates the quality and quantity of pasture they consume. Furthermore, Kenyon *et al*. (2014) added that body weight is related to skeletal size, breed, physiological state, gut fill and length of fleece of sheep. This may mean that the body weight of an animal does not truly reflect its nutritional status (Ndlovu *et al*., 2007). For example, a pregnant ewe with low energy reserves could have a higher weight than a non-pregnant ewe with a moderate energy level. Furthermore, Nicholson and Butterworth (1986) pointed that a large-framed sheep with less fat and muscle reserves may have a higher body weight than a small-framed breed, for example SA Mutton Merino versus Pedi breeds. Despite these, the weight of sheep can guide sheep farmers in taking decisions regarding breeding, feeding and health management (Villiers *et al*., 2009). However, it's quite common to observe that many small-holder farmers in Botswana lack the necessary scales to weigh their livestock before administering antibiotics and anthelminthic treatments. This scenario can lead to either inadequate dosing or excessive administration of drugs in sheep, thus elevating the risk of fostering drug-resistant pathogens. In addition, if sheep farmers rely a lot on visual assessment to estimate weight of their animals, they may also insufficiently feed or late supplement these animals after they have lost much of their body energy reserves (Brown *et al*., 2015).

2.8.2 Body condition score

When the nutritional levels of rangelands do not meet the requirements of sheep, the animals will mobilise their body reserves in form of fats and meat to meet their nutritional demands (Caldeira *et al*., 2007; Kenyon *et al*., 2014). These authors also noted that while estimating the total body reserves from live animal may be difficult, assessing body reserves (fat and skeletal muscles) along the backbone can be achieved by using body condition score (BCS) technique. Russel (1984) showed that the amount the fill or thickness of loin muscles (ribeye) is done by hand, evaluating the degree of sharpness or roundness of the spinous and transverse processes of the lumbar region. Using BCS and body weight in predicting carcass composition of live animals has been hailed as inexpensive, quick, easy and non-invasive. This method had been described as a 5-point scale that put an emaciated and very fat sheep on scores one and five respectively by Kenyon *et al*., 2014 and Brown *et al*., 2015. On contrary, Nicholson and Butterworth (1986) and Ndlovu *et al*. (2007) indicated that 5-point scale is not suitable for tropical breeds as it excludes wide range of animals like those that are very emaciated and very obese and instead found a 9-point scale as alternative. The previous authors also pointed that body condition score gives a better indication of energy status in sheep than its live weight as well as reflects the quality of feed the animal had been consuming over reasonable length of time. Body condition score also showed high correlation to meat energy, fat energy and total energy of carcass than live weight in Pelibeauy ewes in a work by Diaz-Lopez *et al*. (2017). When pointing out the benefits of high body condition score in sheep, Mathias-Davis *et al.*

(2013) indicated that such scores in ewes will increase multiple births and influence high growth rate of lambs. However, Kenyon *et al*. (2014) suggested that in some sheep breeds the relationship between body condition and productivity may be curvilinear instead of being linear.

2.8.3 Level of blood metabolites

It has been found that certain blood metabolites and hormones can indicate the health status and nutritional level in ruminants at that point in time (Ndlovu *et al*., 2007; Caldeira *et al*., 2007; Abdel-Ghani *et al*., 2011). Hence, this may help farmers in identifying animals with metabolic problems, metabolic superior animals on rangelands and those that require supplementary feeding (Ndlovu *et al*., 2007). According to literatures (Caldeira *et al*., 2007; Ndlovu *et al*., 2007; Abdel-Ghani *et al*.,2011), these major blood constituents were categorized as hormones (glucagon, insulin, thyroxine, triiodothyronine), liver enzymes, those related to nutrients metabolism like energy (glucose, beta-hydroxyl butyrate, non-esterified fatty acids, cholesterol and total lipids), protein (total proteins, albumin, globulin, urea and creatinine) and minerals. Evaluation of blood metabolites by smallholder farmers can be challenging since it requires high skilled manpower to take blood samples and process them, depends on availability and costs of sampling ingredients (Ndlovu *et al*., 2007). The authors also found that the level of blood metabolites is influenced by age, physiological status, breed, sex, season and daily nutrient intake. In their research involving Sanga cows, Damptey *et al*. (2014) discovered that high plasma concentrations of urea and low concentrations of creatinine appeared to contribute to the postponement of the resumption of postpartum ovarian cyclicity. Sheep with different ages and physiological status were found to have significantly different total protein, albumin and globulin levels (Abdel-Ghani *et al*., 2011).

2.9 Potential effects of Sunflower seed cake and Canola meal on meat quality of sheep

The quality of meat is critical in satisfying the needs of consumers and these measures of meat quality may include organoleptic, nutritional, safety, commercial, technological and image attributes, according to Prache *et al*. (2021). Wang *et al*. (2021) and Guerrero *et al*. (2013) noted that organoleptic qualities and degree of acceptance of meat is influenced by intrinsic (inherent to the animal like breed, sex, age, weight at slaughter, type of muscle fibres) and extrinsic (inherent to production system, management/stress agents, diet/feeding system, pre- and post-slaughter conditions, way of cooking and consumers' habits and others) factors. Amongst these factors, Wang *et al*. (2021) pointed that diets contribute a significant role in the determination of meat quality. In most feeding systems, SBM is most dominant protein source in animal diets, though very expensive, according to Delele *et al*. (2021). Nevertheless, alternative protein sources including oils seed cakes from canola and sunflower have been reported to adequately provide for the protein need of ruminant animals Sekali *et al*. (2016) found that diets with canola meal produced similar meat quality values in Mutton Merino lambs as with the SBM. In addition, Plaisance *et al*. (1997) and Ponnampalam *et al*. (2005) also made similar observations in lambs fed diets containing canola meal. Moreover, Lima *et al*. (2018) found that diets containing SSC or SBM as main protein sources produced meat with similar meat pH, meat colour parameters, cooking weight loss or Warner-Bratzler shear force. Both sunflower seed cake and canola meal are reported to contain high levels of methionine (Villamide & San Juan, 1998; Khajali & Slominski, 2012) and this amino acid highly influences microbial protein in lamb (Visagie, 2010).

2.10 Summary

Like other indigenous animal breeds in Southern Africa, Tswana sheep is dominantly raised by smallholder farmers as a source of animal protein, income and plays various socio-cultural functions. Even though this breed is adapted to harsh semi-arid climatic conditions, its performance is constrained by various factors like high prevalence of diseases and parasites, poor farm management, very low farming profits and limited forage availability. Reduced productivity and off-take rate in sheep raised on communal rangelands are exacerbated by lack of feed supplementation rates during dry seasons. Different support programmes have been rolled-out by governments to improve feed supply and quality amongst smallholder farmers, like promoting fodder production and utilization of crop residues in animal feeding. Since most dominant crop residues contain high fibre content and low digestible nutrients, it is therefore highly necessary to further investigate different methods of improving nutritive value of their diets and evaluate the effects of such methods extensively on sheep performance. Information regarding the effect of CM and SSC on feed intake, growth performance and meat quality and sensory evaluation of indigenous sheep, like Tswana sheep, is very scarce. It is therefore essential to assess the effects of the substitution levels of CM and SSC as a possible replacement for the SBM in Tswana sheep weaners and determine their optimum inclusion levels to reduce nutrients wastage and physiological stress.

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CHAPTER 3: SHEEP PRODUCTION AND FEEDING PRACTICES AMONGST SMALL-HOLDER FARMERS IN SOUTH-EASTERN PARTS OF BOTSWANA

Abstract

The objective of this study was to investigate the sheep production, sheep production practices and to do an inventory of the available feed resource in the communal areas in southeastern regions of Botswana. A semi-structured questionnaire was used to collect information on farmer's biodata, flock size and composition, main reasons for keeping sheep, major feed resources and feeding practices. The associations among age, level of education, flock size, feeding practices and processing methods were computed using Chi-square tests. Majority of farmers were male (67%), above 50 years old (64%), married (49%), had no formal education (36%) and kept a mean flock size of 40.35±4.01. Findings from the study showed that communal farmers kept sheep mainly for cultural or religious purposes and their high fertility rate. Rangelands were mentioned as the main feed source for the sheep and most farmers supplemented their animals with crop residues (67%) and lucerne/lablab hays (51%). Crop residues utilized were from maize, sorghum and cowpeas stovers and they were mostly milled before feeding. Feeding of proteinaceous hays and processing frequency were significantly associated with flock size. A notable observation was the limited engagement of both youth and women in sheep production endeavours. It is of utmost importance to promote and foster greater participation from these demographics as well as individuals with higher educational qualifications, within the domain of sheep farming among communal farmers. Promotion of utilizing oilseed meals in improving the quality of cereal crop residues was found to be minimal among the farmers and should therefore be encouraged amongst communal farmers. Such

approaches could optimize growth performance of lambs and improve mutton quantity and quality.

3.1 Introduction

In most smallholder areas of Botswana and the world over, sheep are mainly kept for meat, skins and milk (Aganga & Fabi, 2007; Statistics Botswana, 2019) and also used in cultural activities and religious ceremonies (Rasmussen, 2002; Mokgoba, 2014; Legodimo *et al*., 2016). Sheep are the least reared ruminant animals in Botswana with a total population of 234 621. Majority of sheep (59.0%) are found in Gaborone and Southern regions of Botswana. The Tswana breed is the most common sheep breed (62.8%) kept by smallholder farmers (Statistics Botswana, 2019). Its dominance in these regions may be associated with the huge social value and economic potential to smallholder farmers, mostly driven by cultural and religious uses complemented with the demand for mutton that may provide healthy dishes with low cholesterol levels for consumption by urban and peri-urban dwellers. Generally, there is high demand for live sheep rather than carcasses in many communities in Botswana as they allow the provisions for harvesting offals (organ meats) for traditional dishes (Van Heerden *et al*., 2014). Therefore, sheep production has the potential to contribute significantly to smallholder economies and ensure food security in the smallholder sector.

Although sheep have the potential to significantly contribute to food security in numerous smallholder regions of Botswana and Southern Africa as a whole, farmers encounter a multitude of challenges in sheep production. Among other factors, reduced abundance and poor-quality feed resources, coupled with diseases have hampered sheep productivity in many small holder areas. In Botswana, the highly productive areas for animal feed resources are also densely populated. The human population in these areas account for 47% (1 020 732) of the country’s total population (Statistics Botswana, 2018), a scenario that has the potential to reduce sheep carrying capacity on rangelands while causing increased stocking density (Talbot, 1986; Tripathi & Rani, 2018). Consequently, this may lead to overgrazing, land degradation and low forage yield, ultimately affecting sheep production performances. Consequently, poor growth, high rate of abortions and high mortalities in lambs, pregnant and lactating ewes are prevalent in sheep herds. Moreover, animal losses are also incurred due to road accidents and poisoning amongst sheep grazing along roads and scavenging on industrial wastes dumped on rangelands.

Increasing the current level of productivity of sheep is imperative if food security and household income is to be assured in smallholder areas (Mthi & Ngangiwe, 2018). This could be achieved through provision of sheep with good quality feed throughout the year. However, conventional feed sources and supplements that offer balanced nutrients for sheep are often cost-prohibitive and unattainable for smallholder farmers. Nevertheless, there is substantial potential in alternatives like crop residues and agro-industrial by-products to enhance both the quantity and quality of available feed sources for sheep (Aregheore & Chimwano, 1992; Legodimo *et al*., 2016; Abera *et al*., 2018). In the southern regions of Botswana, there is huge opportunity in this regard, as the regions account for up to 67.1 % maize (662 vs 987 MT) and 51.1 % beans/pulse (298 vs 583 MT) grains of the national produce from traditional sector (Statistics Botswana, 2019). These regions thus house a significant portion of the food and feed industries, which are capable of supplying agro-processing by-products that can be harnessed for incorporation into sheep diets. However, despite the potential of sheep production in the southern regions of Botswana, information on the inventory of feed resources for indigenous sheep kept by farmers is inconsistent. Moreover, very little scientific investigations have been done on the identification and analysis of main sheep production constraints and opportunities with little or no influence on further research and agricultural policy reforms. Data on feed resources and sheep feeding practices under smallholder farmers in highly populated villages and peri-urban areas is also limited. Therefore, the objectives of this study were to identify and analyse sheep production practices, constraints and opportunities in smallholder areas in the southern regions of Botswana. The study also intended to investigate feed practices and the main feed processing methods adopted by sheep farmers in these areas.

3.2 Materials and Methods

3.2.1 Description of study site

A comprehensive survey was conducted across all four agricultural districts present in the Southern and Gaborone regions, situated in the southeastern part of Botswana. The Southern and Kweneng districts are situated within the Southern region, whereas the Kgatleng and South East districts are situated within the Gaborone regions. The two agricultural regions are in the hardveld and sandveld ecological zones of Botswana (Figure 3.1), with the hardveld parts dominated by arable farming due to its highly fertile soils while less fertile soils (sandveld parts) are mainly to pastoral farming. The average rainfall in the south-eastern regions is 450mm/year, with the very hot (30 - 40^{0}C) and cold (11 – 12 ^{0}C) temperatures usually recorded January –December and June –July periods respectively (Statistics Botswana, 2015; Maboa, 2016; World Climate Guide, 2020). The regions may occasionally experience below-zero temperature at winter-nights (June-July) resulting in frost (Jain *et al*., 2006). The dominant vegetation cover in these regions was savanna biome featuring Acacia and broad -leaved deciduous woodlands.

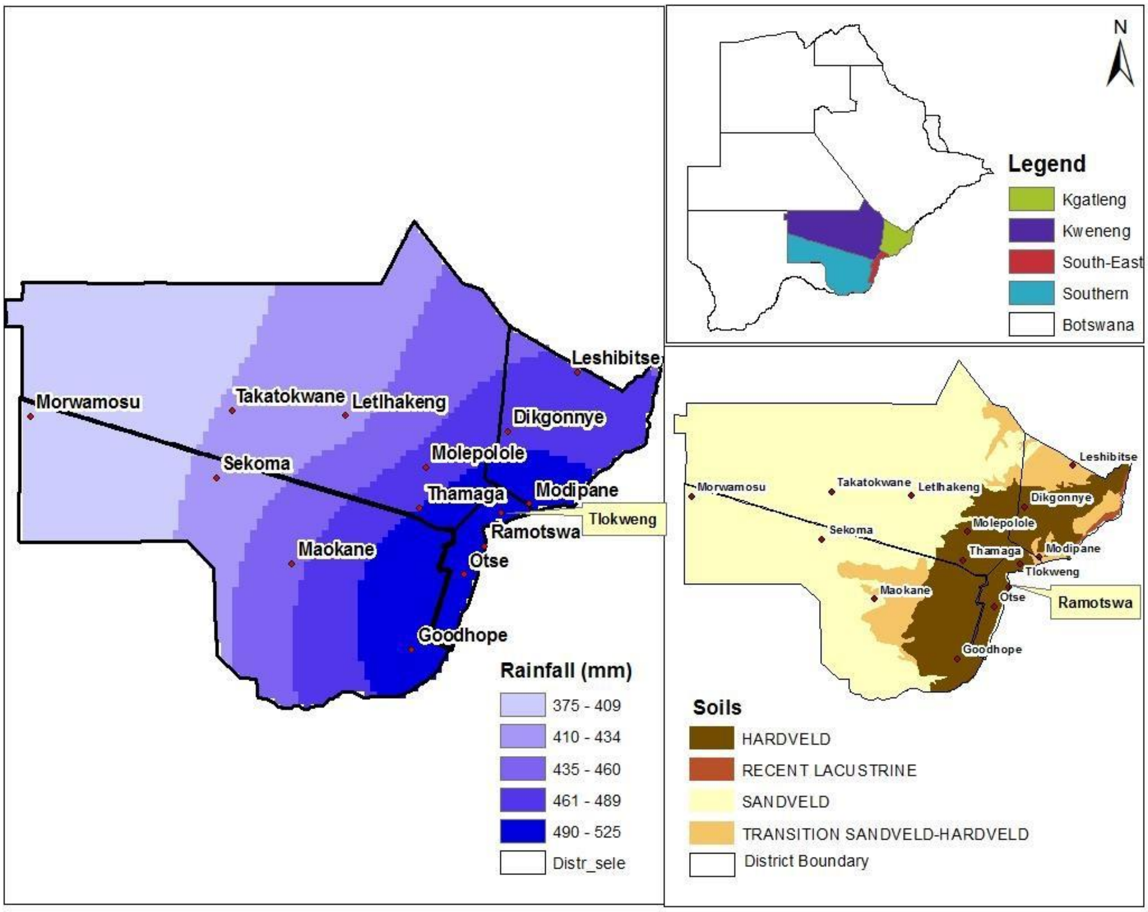

Figure 3. 1 Location map showing rainfall distribution and soil landscape of agricultural districts in southeastern regions of Botswana

(prepared by I.T. Makoi, Department of Wildlife and Natural Resources, BUAN)

3.2.2 Sampling of respondents

The participants in the study were chosen based on their ownership or custodianship of sheep, as these factors played a crucial role in influencing their decisions related to sheep husbandry practices and marketing strategies. Due to the high costs involved and time face-to-face interviews were limited to a total of hundred (100) smallholder sheep farmers. These farmers were selected purposively based on knowledge and experience in sheep production with the help of extension officers from Department of Veterinary Services in the survey regions and they all signed a consent agreement for the interviews. Southern District houses two (2) dominant tribes (Bangwaketse and Barolong), hence it was further divided to produce Jwaneng and Goodhope ‘districts’ to capture farming practices inherent with these tribes. Two (2) villages were selected from each ‘district’ and from each village ten (10) communal sheep farmers were interviewed. The following were villages selected; Modipane and Oodi (Kgatleng), Tlokweng and Otse (South East), Goodhope village and Metlobo (Goodhope), Maokane and Morwamosu (Jwaneng) and Molepolole and Letlhakeng (Kweneng).

3.2.3 Data collection

A semi-structured questionnaire was used to obtain information on farmers’ demographics, sheep production practises, flock size, breeds kept, reasons for raising sheep and feed resources and feeding practices as well as feed processing methods adopted by the communal sheep farmers. The interviews were conducted in a face-to-face manner using structured and open-ended questionnaires. The questions were read aloud by the interviewer in farmers’ vernacular language and in the presence of their extension officers. The answers were recorded after some verification. Visual assessments of fodder barns and rangelands were done across all sampling points to estimate the quantity and quality of forage.

3.2.4 Data Analysis

Data on farmer demographics, production practices, sheep distribution, feed resources and feeding were analysed using descriptive statistics of the Statistical Package for Social Scientist (SPSS) version 25.0. Categorical variables within the group were compared using cross tabulations and correlations. Chi-square and Pearson’s correlation analyses were used to test associations between age, education, flock size, feeding practices and processing methods.

3.3 Results

3.3.1 Farmer demographics

The results on farmer demographics are presented in Table 3.1 and Figure 3.2. From these results, it is clear that most smallholder farmers in the surveyed regions of Botswana were males (67%) and above 51 years of age (61%) while 3% was below the age of 30 years (Table 3.1). Forty-nine percent of the farmers were married, while significantly, 15% were widowed. The study also found most sheep farmers in study area received no formal education, while very few farmers (13%) had tertiary education (Figure 3.2). In addition, most farmers with tertiary education were mostly young farmers There was a strong association between the age and educational qualifications with a strong inverse relationship observed between education and age of the farmers (r = -0.618, $P<0.001$). There was also a strong positive association between educational qualification and the sheep breed kept (r = 0.317**, $P<0.001$).

3.3.2 Sheep flock composition and breeds

Table 3.2 shows that, on average, communal sheep farmers kept forty (40) sheep, with the largest proportion (54%) made of both ewes (both young and adult) followed by lambs (25.8%), castrate (16.8%) and rams (4%). The flock size was found to be directly correlated to the purpose of meat production for consumption by farmers ($P<0.05$). Nevertheless, the average flock sizes were not indicative of the desire of communal farmers to increase animal sales and make profit as evidenced by an inverse relationship (r = -0.225, $P = 0.024$) between flock size and commercial reasons for keeping sheep.

Table 3.1 Distribution of personal characteristics of smallholder sheep farmers in Gaborone and Southern regions

Gender	%	Age (years)	%	Marital status	%
Male	67	≤30	3	Married	49
Female	33	31–40	17	Single	35
		41–50	16	Divorced	1
		51–60	30	Widowed	15
		>60	34		

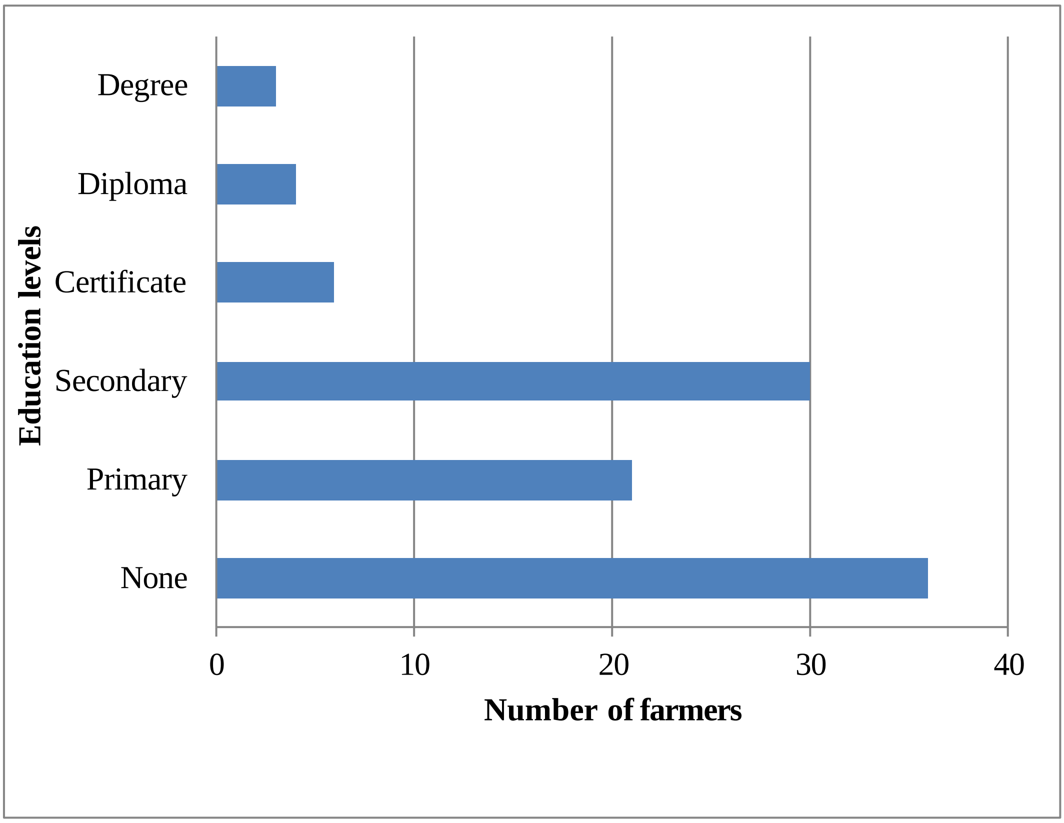

Figure 3. 2 Education levels of communal farmers in Gaborone and Southern regions

Table 3.2 Sheep flock size and composition

Animals	Min	Max	Mean	Std dev
Rams	0	5	1.61 ± 0.11	1.12
Females	2	143	21.90 ± 2.31	23.14
Castrates	0	40	6.77 ± 0.83	8.29
Lambs	0	98	10.43 ± 1.39	13.89
Overall	3	250	40.35± 4.01	40.62

The dominant sheep breed kept by communal farmers was Tswana ecotype (Figure 3.2), followed by its crosses while exotic breeds and their crosses were kept by 15% of farmers. It was also observed that the breed of sheep kept by communal farmers had a direct association with their educational level (χ^2, 28 =66.90, P <0.05) as well as the flock size (χ^2, 28 = 69.99, P <0.05). It was also noted that the breed of sheep amongst farmers was negatively correlated to farmer's age (r = -0.199, P <0.047) and positively correlated to flock size (r = 400, P <0.001).

3.3.3 Reasons for keeping sheep

Based on the results, the primary reason reported for keeping sheep was cultural or religious in nature (Table 3.3). Keeping sheep for cultural reason was directly associated with the farmers' age and education level (P<0.05). Though commercial reason was the lowest ranked reason, this was strongly influenced by the gender of farmers (P<0.001) and was inversely related to education level (P<0.05). Regarding the influence of animal attributes on the choice made by farmers for keeping sheep over other animals, almost half (49.7%) of the total number of farmers preferred sheep because they believed that sheep were highly fertile when compared to the other domestic animals (P<0.05%).

3.3.4 Feed resources for sheep

Table 3.4 presents the various feed resources available for supplementing the sheep in the study area. The findings indicate that the primary source of feed for the sheep was reported to be the rangelands. Most farmers mentioned that crop residues were the main supplementary feed resource for their sheep. The farmers pointed out that rangelands were not adequately providing feed for animals throughout the year despite being generally regarded as source of feed for the sheep in most rural communities. Sixty-seven percent of farmers (67%) mentioned that they were able to supplement their sheep with crop residues, with maize and cowpeas stovers being utilized for feeding by almost two-thirds of smallholder farmers. However, the feeding practices adopted by farmers in this study were not associated with their age or education levels.

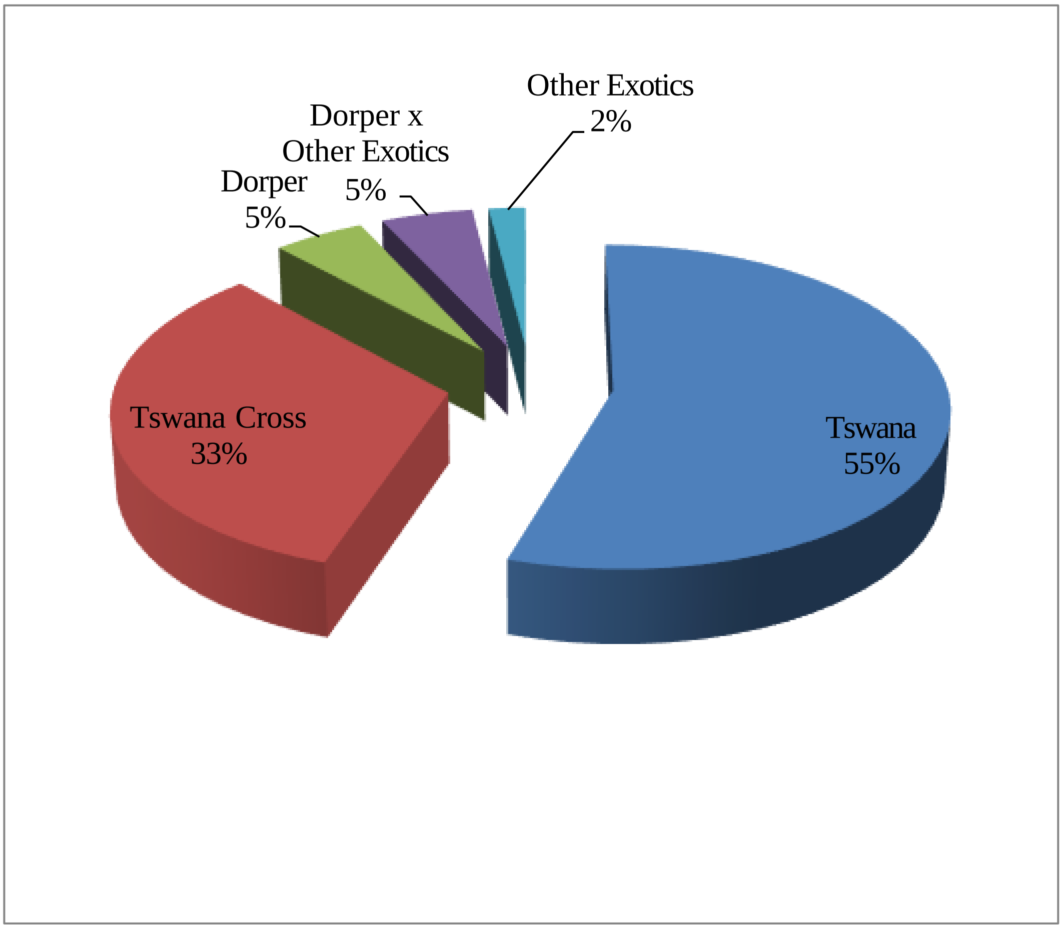

Figure 3. 3 Proportion of communal sheep farmers by type of breed

Table 3.3 Main reasons for keeping sheep and their relationship with farmers' characteristics

Reasons	Responses			Correlation (n=100)		
	Frequency	Ranking	%	Gender	Age	Education level
Farmer related (n=88)						
Prestige	20	2	22.72	-0.021	0.064	0.000
Cultural/Religious	54	1	61.36	0.099	-0.208*	0.229*
Commercial	14	3	15.91	0.334**	0.094	-0.200*
Animal related (n=149)						
Growth rate	12	3	8.05	-0.003	-0.131	-0.105
Fertility	74	1	49.66	-0.222*	0.010	0.057
Meat Quality	63	2	42.28	0.123	0.004	-0.002

*Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level

Table 3. 4 Availability of feed resources amongst traditional farmers during the year

	Responses (%)	
Feed Resources	Yes	No
Availability of Feed throughout the Year (N=99)	20.2	79.8
Main Feed Resources (100)		
Crop Residues	67	33
Grass Hay	4	96
Lucerne/Lablab	51	49
Protein Concentrates	4	96
Protein/Mineral Blocks	24	76
Brans/Molasses	37	63
None	20	80
Feeding Oilseed meals (N=97)	3.1	96.9
Dominant Crop Residues (N=100)		
Maize	63	37
Sorghum	34	66
Cowpeas	56	4

Amongst the proteinaceous feed sources, the farmers fed dry forages (lucerne and lablab hays) more often than protein concentrates. However, the analysis of this study also showed that choice of feeding these proteinaceous forages was associated with flock size (P <0.05). The similar trend was also found in the choice of feeding high energy feeds (brans/molasses) (r=-0.284**; P=0.004).

Figure 3.4 indicates that most farmers preferred to supplement their animals on a daily basis, and this was mostly done to confined lambs during the day when the flock was out for grazing. Farmers who had limited access to supplements often adopted a practice of supplementing their animals once a week. This approach coincided with their routine (weekly) medical check-ups or engagements outside their farms. It was also observed that most farmers (95%) could not afford to supplement their animals throughout the year. However, farmers who had stored crop residues preferred to supplement their animals during dry period (winter - spring seasons) (Figure 3.5). There was significant association (P=0.002) between processing of crop residues with sheep number kept by communal sheep farmers in the current study. According to Figure 3.6, most communal farmers milled their crop residues before feeding them and majority of them reported that they used hired hummer mills from their localities. About 44% of farmers expressed a preference for mixing milled crop residues with salt, bran or molasses. Conversely, a small number of farmers indicated that they refrained from processing their crop residues before feeding due to the high costs associated with hiring hummer mills. Instead, these farmers preferred to harvest cowpeas vines, as they found it convenient to feed without requiring milling.

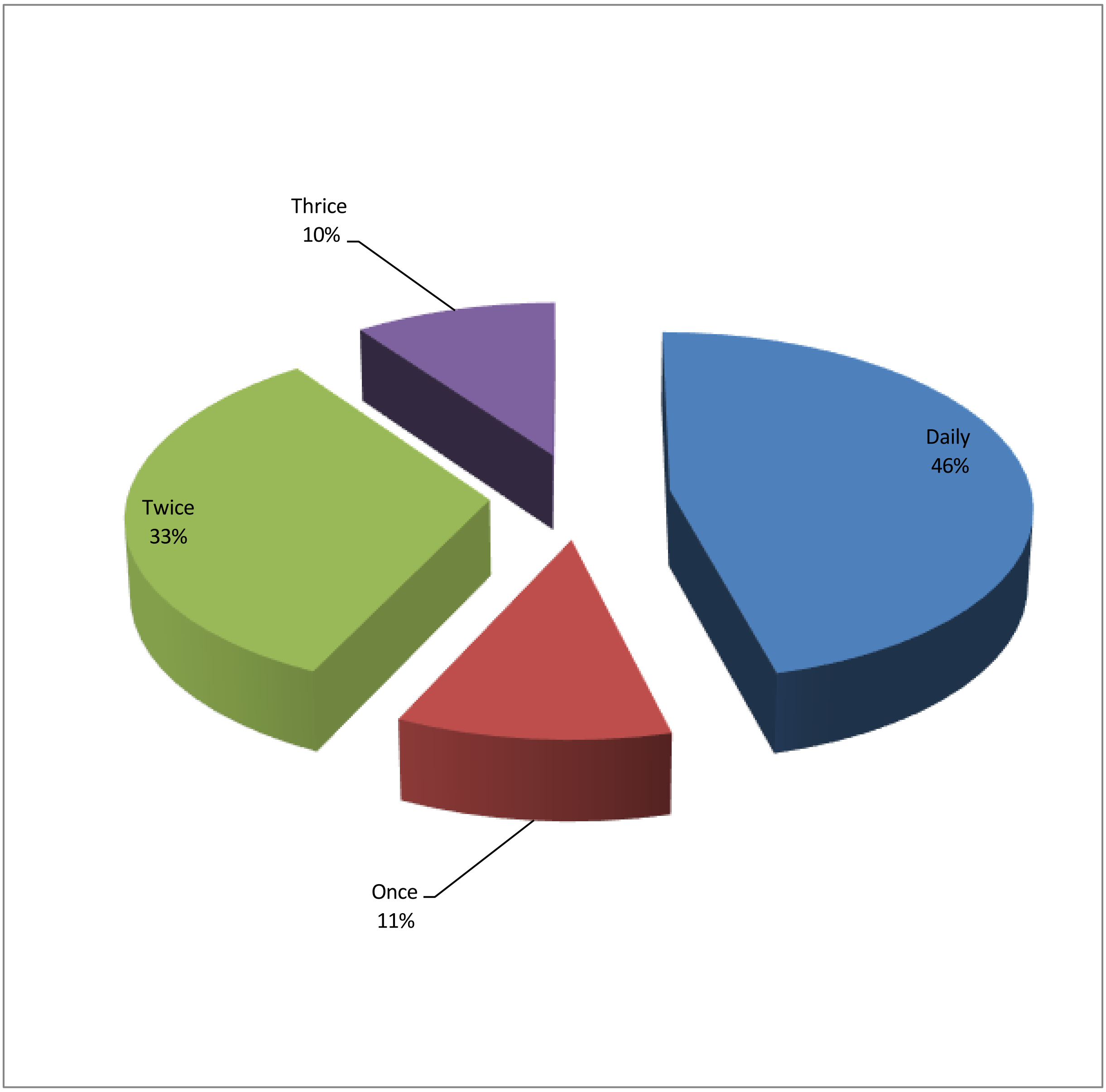

Figure 3. 4 Frequency of feeding sheep per week by communal farmers

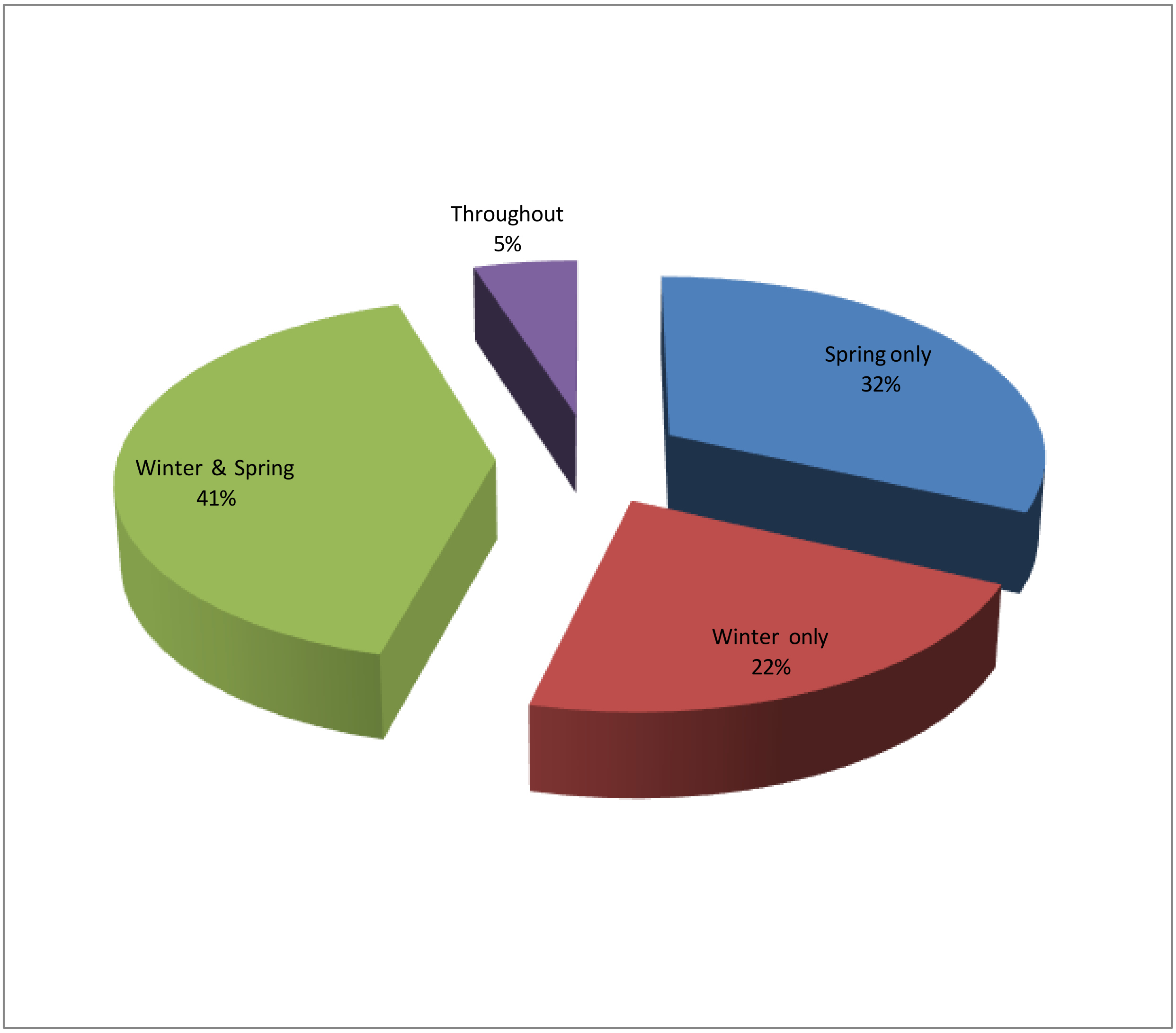

Figure 3. 5. Seasonality of feeding communal sheep with crop residues

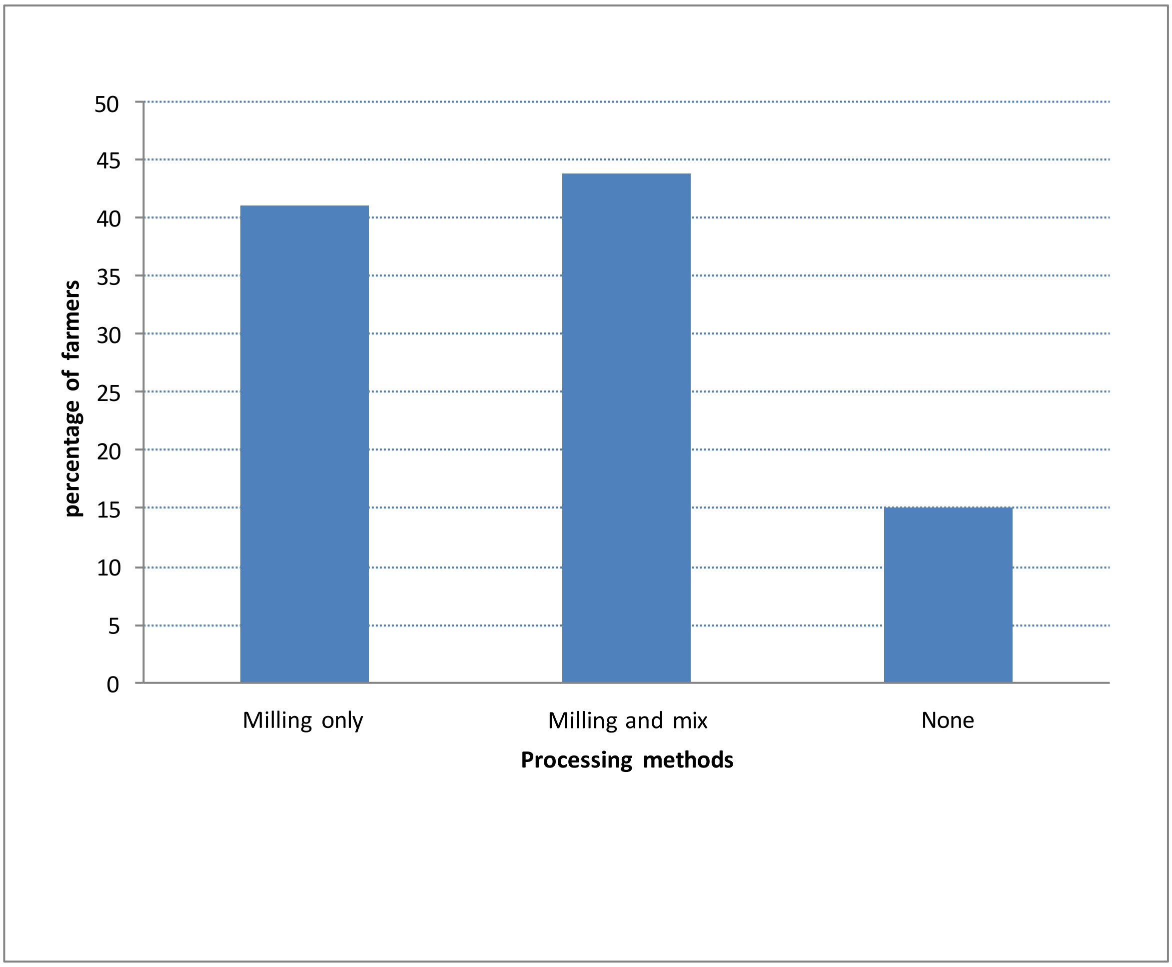

Figure 3. 6 Percentage of smallholder farmers processing crop residues

3.4 Discussion

3.4.1 Socio-economic characteristics of respondents

Socio-economic demographics showing a high proportion of males involved in livestock farming activities in the current study are consistent with previous observations in the same regions in 2017 (Statistics Botswana, 2019), but with slight variance with the findings of Oladele and Monkhei (2008). Generally, a slight increase in households headed by women in the smallholder farming sector was observed and this may be attributed to the adoption of various governmental initiatives directed at encouraging women into small stock farming like Livestock Management and Infrastructure Development (LIMID) and special Integrated Support Programme for Arable Agriculture Development (ISAAPAD). Results of the current study are also consistent with finding by Mthi and Ngangiwe (2018) who observed regional male farmers' dominance in smallholder sheep farming (72.6%). Similar observations were made in Ghana (Baah *et al*. (2012) and in Ethiopia (Lakew *et al*., 2017). Mthi *et al*. (2017) concluded that high number of male farmers in sheep farming could be as a result of cultural influences and inheritance practices of transferring livestock to male heads of families. The limited involvement of women in sheep farming has frequently been associated with their substantial engagement in daily household tasks (Fayemi & Muchenje, 2013). This may also be due to the physical nature of raising livestock on daily basis that deter women from sheep farming, including rounding up sheep on daily basis from grazing area and inspecting them for any abnormalities.

The findings on farmer age and literacy in the current study are consistent with findings elsewhere (Mthi & Ngangiwe, 2018; Lakew *et al*., 2017). The high participation of old and illiterate farmers in sheep farming often reduces adoption rates of new farming technologies and marketing skills designed to improve sheep productivity and farm profits under smallholder farming (Ngqualana & Obi, 2019). High illiteracy rates also have the potential to increase food insecurity in developing countries like Botswana and exacerbate poverty rates in the rural areas. This is also consequential to the increased risk for debilitating health conditions within communities. Limited involvement of young active groups (≤40 years) and those with tertiary education could be explained by their high preference for securing formal employment in urban areas. This choice is often favoured due to its perceived reliability in providing a steady income to establish families and ensure housing stability, in contrast to pursuing livestock farming. Comparable findings by Scholtz *et al*. (2008) and Katiyatiya *et al*. (2014) indicated high participation of old livestock farmers in communal areas. However, Abd -Allah et al. (2019) found a contrasting scenario in which illiterate farmers were fewer (14%) in traditional goat farming in Egypt. This high involvement by young and educated people in farming in Egypt compared to this country may be attributed to differences in socio-economic value of small stock, government initiatives and marketing channels. These are likely to reduce production costs and improve farming profits in small stock industry.

3.4.2 Sheep flock structure and breeds

Sheep flock size obtained in this study was double than that reported for 2017 in the same region by Statistics Botswana (Statistics Botswana, 2019). The noted rise in the sheep population within the present study might be attributed to higher rates of new sheep introductions into the study area, achieved through purchases, as well as the increased adoption of Poverty Eradication and Special ISPAAD programs by farmers in the same region. These government initiatives encourage resource-poor people to own livestock and improve food security at home level. Large flock size is considered beneficial to smallholder farmers as it reduces inbreeding rates and optimizes genetic gain within the flock (Adebe *et al*., 2020). In addition, the observed high number of farmers who preferred to keep more sheep for production of meat for consumption may imply high preference for mutton amongst communal farmers. The observed high proportion of female sheep in the current study work may indicate that smallholder farmers prefer to retain ewes for breeding purpose. The findings on flock composition in this study are similar to those reported by Mthi *et al*., (2017) in communal areas in South Africa and elsewhere (Kenfo *et al*., 2018). This study also identified a reduced count of lambs among the sheep kept by communal farmers. This occurrence might be attributed to elevated lamb mortalities and a shortage of breeding ewes in the communal farming context (Lakew *et al*., 2017). Nevertheless, this proportion of lambs is similar (24.18%) to that observed by Nsoso *et al*. (2004) in Botswana and lower than 36.3% found in the study by Kenfo *et al*. (2018) in Ethiopia. This difference might be due to a variance in participation rate of young farmers and literacy rate amongst sheep farmers between the two studies and hence divergence in exposure to new and improved production management practices related to survival rates of lambs.

The current study also revealed high preference for Tswana breed amongst communal farmers and this may be ascribed to its hardiness and fecundity under arid climatic conditions and resistance to most diseases and parasites found in this country (Nsoso *et al*., 2004; Alves *et al*., 2013) added to its good mothering ability. Dominance of indigenous sheep breeds amongst smallholder farmers was also noted in Statistics Botswana (2019) and Molotsi *et al*., (2017) in Botswana and South Africa respectively. The findings of this study also indicate that this breed is predominantly kept by elderly farmers and those with lower levels of educational. This may be influenced by survival rates of this breed under poor nutritional conditions common in communal rangelands as well as low inputs required by farmers to raise this breed.

3.4.3 Main reasons for keeping sheep

From the study, the main objective of raising sheep was to meet cultural and religious functions and to a smaller extend for income generation. Sheep are normally used in social ceremonies like weddings, funerals and occasional (family and friends) parties as well as ritual ceremonies (making communications with ancestors in times of sorrow, illness and happiness). On the contrary, Lakew et al. (2017) and Mapiliyao et al. (2012) reported a different perspective in their studies. They observed that the primary motivation for engaging in sheep rearing in Ethiopia and the Eastern Cape province of South Africa, respectively, was the generation of income. In terms of reproduction performance, most farmers mentioned that sheep were highly fertile and produced good quality meat when compared to cattle and goats which are often affected by seasonality in quantities and quality of feed. This can be attributed to the ability of the typical fat-tailed Tswana sheep which can gradually mobilise and utilise their tail fat to ensure a steady energy supply over extended periods of limited feed availability (Atti *et al*., 2004; Alves *et al*., 2013). Hence, they are more likely to maintain good body condition score and hence more fertile (Aliya *et al*., 2012) and produce high quality mutton (Ullah *et al*., 2019).

3.4.4 Main feed resources and feeding methods

Findings of the study showed that most farmers indicated natural pastures as dominant feed resource in their regions, which is consistent with observations by Mosimanyana and Kiflewahid (1985) and Aganga *et al*. (2005). However, the reported increase in use of lablab hay, lucerne hay and brans/molasses in sheep supplementation programmes could be a reflection of positive responses to increased provision of government farming subsidies under ISPAAD (Integrated Special Program for Arable Agriculture Development) and Drought

Relief scheme (Statistics Botswana, 2019). Oil seed meals were the least (3.1%) supplemented feed by sheep farmers and this can be attributed by the high prizes associated with them and hence most farmers cannot afford them as observed previously (Statistics Botswana, 2019; Ben Salem, 2010; Mthi & Ngangiwe, 2008; Ngqulana & Obi, 2019). Low rates of supplementation of sheep have the effect of limiting expression of their full genetic potential and reduce farming profits.

Observations from the study show that the majority of sheep farmers who could afford to supplement their animals did so on daily basis and during dry seasons. According to respondents, this practice was mostly confined to kraaled lambs which were provided with brans/molasses and cowpeas residues as the most common supplements. Locally, these residues had been reported to be highly nutritious (19.5% CP) (Legodimo, 2013) and could meet protein requirement levels of 18% CP found to be sufficient for pre-weaner lambs raised under semi-arid regions (Santra & Karim, 1999). Hence, adopting this feeding practice is likely to enhance the weight gains of lambs and consequently improve the overall returns in sheep farming.

Lack of harvesting machineries and good storage facilities amongst local smallholder farmers may be contributing to harvesting of low amounts of crop residues and hence insufficient supply to sustain sheep throughout the year. Field observations during the study showed that most farmers store crop residues in open areas, predisposing these crop residues to damage by termites and moulds as observed in other studies (Tesfaye & Chairatanayath, 2007). Crop residues that have developed moulds are likely to reverse the benefits of harvesting the residues as well as affect their quality hence reduce feed intake and utilization, lowering rumen functionality and increasing potential of animal infections (Gallo *et al*., 2015). Consequently, these will lower reproductive performance, lambing percentages and general productivity of sheep (Smith *et al*., 1990). The study also revealed that a small number of farmers refrained from processing crop residues. This aligns with the findings of Tesfaye and Chairatanayath (2007), who identified constraints related to processing crop residues. These constraints included a lack of knowledge regarding the methods' utility and benefits, concerns about labour costs and limited financial resources to acquire machinery such as hammer mills and mixers. However, improved rates of ownership and use of hammer mills, promoted by support package under LIMID programme, with increased possibility of hiring them by other farmers might have contributed to better rates of physical processing of crop residues in the study area. Milling reduces the feed particle size of crop residues and thus reduces feed wastage, increases feed intake and digestibility (Smith, 1989; Tafaj *et al*., 2001). In addition, mixing ground cereal stovers with oilseed meals influences high rumen population (Oliveira *et al*., 2006; Khalid *et al*., 2011), high microbial protein and improved weight gain in ruminants (Stern *et al*., 2006).

3.5 Conclusion

The study revealed that the majority of communal sheep farmers were older and lacked formal education. Additionally, they were predominantly male and were engaged in rearing indigenous Tswana sheep. An increase in the number of female households involved in sheep production was also observed. The main reasons for keeping sheep by communal farmers were for cultural or religious purposes and high fertility rate. Majority of farmers in this study indicated that rangelands could not sustain their animals throughout the year and hence supplemented their sheep with crop residues and lucerne/lablab hays. Dominant crop residues accessed by farmers were maize stover, sorghum stalks and cowpeas and on most occasions the farmers fed crop residues after milling them. Very few farmers supplement their sheep with the conventional oilseed meals as they were reportedly expensive. Generation of more information on use of alternative oilseed meals in livestock feeding locally could improve awareness on their nutritional qualities and possibility of adoption amongst communal farmers.

Hence, there is a great need to conduct comprehensive research into the use of oilseed meals to enhance the nutritional value of crop residues fed to sheep. Additionally, these inverstigations would extend to assessing the impact of such practices on sheep productivity, especially during times of limited feed availability on the rangelands.

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CHAPTER 4 - EVALUATION OF RANGELAND CONDITIONS, FORAGE QUALITY AND NUTRITIONAL STATUS OF SHEEP RAISED BY COMMUNAL FARMERS DURING THE DRY SEASONS IN BOTSWANA

Abstract

The objective of the current study was to assess the rangeland conditions, forage quality and nutritional status of sheep in communal lands during the dry seasons. The investigated rangelands were assessed following a pioshere procedure at 0.5 km, 1.0km and 3.0 km away from main watering point. They had an average herbaceous yield of 1017.00kg/ha and low crude protein content and high amount of lignin. It was also observed that herbaceous forage yield, neutral detergent fibre and acid detergent fibre levels increased (P<0.05) with decreasing grazing pressure from the main water sources across all districts. Furthermore, herbaceous biomass yield was affected (P<0.05) by districts, with the highest (2360 kg/ha) and lowest (221.28 kg/ha) values observed in the Southern and South East Districts respectively. High mean canopy cover (70.63%) of the study area suggested that it was bush-encroached, a situation that may result in insufficient feed supply to grazing animals. Live body weights of all sheep except adult ewes were influenced (P<0.05) by their district of origin, with adult pregnant and suckling ewes in the Southern districts (48.55 kg and 43.44 kg) being heavier (P<0.05) than their counterparts in the South East and Kweneng districts that weighed (40.39 kg and 36.67 kg) and (39.78 kg and 35.56 kg) respectively. This was consistent with difference (P<0.05) in feed supply amongst the investigated districts. Similarly, this may have led to difference (P<0.05) in BCS of sheep between the Kgatleng and South East districts. Contrasting feed supply might have resulted in varying total nutrients intakes between the researched sheep. Lowest feed supply in the South East district, might have led to lowest

nutrients intake and intense mobilization of protein and energy reserves amongst the sheep. Hence, they exhibited highest (P<0.05) values of creatinine (62.96 mmol/l), BUN (5.72 mmol/l), glucose (1.39 mmol/l) and cholesterol (1.41 mmol/l). Furthermore, the observed high levels of total protein (68.61 - 72.08 g/l) showed low hydration status amongst study animals, consistent with the seasonal effect during the sampling period. Again, high concentrations of bilirubin (4.25 - 5.08 micromol/l) and GGT (44.02 - 66.09 U/l) across all districts demonstrated high incidence of chronic liver helminthiosis amongst most sheep in the study region. Results suggest that the rangelands of the study area had high bush-encroachment and thus had extended feed scarcity and low nutrients supply during dry seasons.

4.1 Introduction

About two-thirds (59.0%) of the estimated 235, 000 traditional sheep can be found in the South-Eastern (SE) regions of Botswana (Statistics Botswana, 2019), with natural pastures as their main feed resource. The SE regions of Botswana are highly populated, with the ever-expanding urban and peri-urban settlements continuously encroaching into agricultural areas and thus reducing grazing areas at a high rate. This scenario holds the potential to lead to low feed supply in the grazing areas, a situation that may be worsened by the frequent occurrence of long dry periods in the country. During the dry periods, there is reduced abundance and quality of the available feed resources for sheep resulting in reduced growth rate, reproduction performance and in general, the immunity level of sheep is often affected heavily by low nutrients supply from the rangelands (Gulland, 1995; Paul & Dey, 2014). Ultimately, pregnant ewes are forced to use their body reserves to satisfy nutritional requirements for maintenance and pregnancy purposes (Kenyon *et al*., 2012). Consequently, the depletion of body reserves usually leads to low body condition score of ewes, high rates of abortions and neo-natal deaths as well as weak and stunted lambs (Bocquier *et al*., 1987; Kenyon *et al*., 2012; Mathias-Davis *et al*., 2013).

Therefore, farmers need to employ supplementation strategies in their sheep to avert poor reproduction and overall performance of the sheep. In particular, supplementary feeding of ewes in their late pregnancy stage is highly essential due to support accelerated foetal growth (more than 80%) during the last trimester of pregnancy (Robinson *et al*., 1999).

While some farmers do supplement their sheep flock, it is common to find them practising blanket supplementary feeding to all sheep in the kraal. This occasionally results in males and lactating ewes eating more or less than their nutritional requirements respectively. Unless precision supplementary feeding is adopted in sheep farming, underfeeding and excessive feeding may continue to limit genetic potential of sheep and profitability of sheep enterprise (Coetzee, 2013). To ensure the effectiveness of strategic feeding practices in sheep, it is essential to conduct a thorough nutritional assessment of rangeland conditions and the quality of available forage, which includes evaluating the nutritional value of crop residues as well. Subsequently, there is need to assess the nutritional and health status of the animals through determination of their body weights, changes in body condition and concentration of some serum metabolites which are often considered as biomarkers for measurement of nutrient sufficiency in animal body systems (Ndlovu *et al*., 2007; Abdel-Ghani *et al*., 2011; Damptey *et al*., 2014). Physiological biomarkers such as blood glucose, blood urea nitrogen (BUN), creatinine, cholesterol and total protein are crucial blood metabolites when assessing the nutritional profile and overall welfare of animals.

Based on the information provided, it can be hypothesised that rangeland conditionsand quality of available feed resources may affect animal body weights changes, body condition and nutrition related physiological biomarkers in sheep. Information on the quality of rangeland feed resource may assist local smallholder farmers in making decisions regarding strategic feeding of sheep raised on their rangelands. However, such information is very scarce locally, making it difficult for farmers and other stakeholders in the animal production industry to make appropriate recommendations regarding strategic feeding and improvement of sheep productivity. Therefore, the objective of the study was to conduct an assessment of rangelands conditions, generate data on available forage yield and nutritional profiles, body weight changes, body condition and assessment of nutritional status of sheep kept by smallholder farmers.

4.2 Materials and Methods

4.2.1 Site Description

The study was conducted in communal areas of the Kgatleng, South East, Kweneng and Southern districts of Botswana (Figure 3.1 in Study 3) during two separate periods (April/May and August/September). These regions are characterised by wet season occurring from October to March (500mm/year) and dry season (April to September) and the seasons are characterised by high temperature range (30 - 40^{0}C) recorded in January – December period (Statistics Botswana, 2015; Maboa, 2016; Botswana Climate Guide, 2020). Available information also indicates that the coldest temperatures (11 - 12 ^{0}C) occur in June – July months and the larger part of the year (May to September) constitute the dry period. The dominant vegetation cover in these regions was savanna biome featuring Acacia and broad-leaved deciduous woodlands as described in Table 4.1.

Table 4. 1 Density and relative mean density of dominant plant species in South-Eastern regions of Botswana

Region	Botanical Name	Mean Density per hectare (MD ha-1)	Relative Mean Density (RMD (%)	Morphological category
Gaborone	*Dichrostachys ceneria*	204	20.14	I
	Turraea obtusifolia	188	18.56	III
	Acacia mellifera	92	9.08	I
	Acacia tortillis	76	7.50	I
	Acacia erubescens	59	5.82	I
	Acacia robusta	41	4.05	I
	Combretum	41	4.05	II
	apiculatum	39	3.85	I
	Acacia nilotica	39	3.85	III
	Euclea undulata	37	3.65	II
	Terminalia serecia	36	3.55	III
	Grewia flava	24	2.37	III
	Grewia retinervis	24	2.37	V
	Maytenus heterophylla	23	2.27	IV
	Peltophorum	19	1.88	I
	africanum	**1013**	**100**	
	Acacia caffra			
	Total Species			
Southern	*Acacia melliefera*	97	21.75	I
	Grewia flava	74	16.59	III
	Acacia tortillis	46	10.31	I
	Bauhinia petersiana	39	8.74	IV
	Dichrostachys ceneria	26	5.83	I
	Acacia erioloba	23	5.16	I
	Acacia erubescens	19	4.26	I
	Terminalia serecia	18	4.04	II
	Euclea undulata	16	3.59	III
	Acacia caffra	14	3.14	I
	Tarchonanthus camphoratus	14	3.14	II
	Acacia nilotica	10	2.24	I
	Boscia albitrunca	9	2.02	II
	Ehretia rigida	9	2.02	V
	Maytenus heterophylla	8	1.79	V
	Total Species	**446**	**100**	

Morphological category (1 Acacias, 2 tall dense canopy spp, 3 small dense canopy spp, 4 tall open canopy spp, 5 small open canopy spp), according to Meyer *et al*. (2013)

4.2.2 Rangeland composition assessment, herbaceous Biomass Yield and Nutritional Analysis

Herbaceous forage (grasses and forbs) sampling in the rangeland was done based on the following piosphere procedure described by Lange (1969), at three (3) different points (0.5 km, 1.0 km and 3.0 km) away from main watering point (borehole/dam) chosen randomly. From each watering point, two transect lines were made running in opposite directions and a big sampling quadrat (30 m x 30 m) was identified. From the big quadrant, a 0.5m by 0.5m sub quadrat was used for forage samples collection from five (5) sampling points (from all four corners and centre) by clipping all grass and forbs (Figure 4.1), as close to the ground surface as possible and placed in paper bags. The forage samples were dried in a forced air oven (Ecotherm – Labtec) at 105 ^{0}C for 24 hrs to determine dry matter content (AOAC, 2000) for each 0.5 m x 0.5 m plot then the final yield calculated tons per hectare (t/ha). Thereafter, the samples were ground using a hammer mill equipped with a 1mm sieve. Ground samples from the same sampling point were thoroughly mixed and duplicate representative samples were taken and stored in tightly sealed honey jars at room temperature for later analysis. The samples were analysed for neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) using ANKOM^{200}Fiber Analyser (ANKOM technology, 1998a). The Nitrogen (N) content of forages was measured using Dumas combustion method (method 990.03).

A. South East District

B. Kgatleng District

C. Gaborone region rangeland

D. Sheep and goats going out for grazing in South East District

E. Kweneng District

F. Southern District

G. Southern region rangeland

H. Sheep and goats going out for grazing in Southern District

Figure 4. 1 The condition of rangelands and animals at the beginning of dry and cold season in Gaborone and Southern regions in Botswana

4.2.3 Density and Canopy cover of woody plants

During the August/September period (dry and hot season) of study, the effects of drought were noted to be particularly severe. Basal vegetation, consisting of grass and forbs, was notably scarce in many of the areas that had been previously sampled during the April/May period. Therefore, the woody plants were also considered as significant alternative feed resource. Data on the density and aerial cover of woody plants was therefore estimated. Aerial cover was generally considered an indicator of the relative abundance of plant species, whereas plant density indicated the number of individuals of a species (or all species) within a specific area (National Research Council, 1962). In addition to leaf form and growth patterns, Meyer *et al*. (2013) used woody plants density to categorize woody plants. In their work Abate *et al*. (2012) observed a negative relationship between woody plant density and composition and biomass of grass and forbs. Hence, this study categorized fifteen (15) dominant woody plants species from each region (Table 4.1), according to Meyer *et al*. (2013) and used the table as a guide in the estimation of plant biomass in South-eastern regions of Botswana. Data collection for these two (2) parameters was done on two opposite 30m x 30m plots, located three (3) kilometres away from the selected main watering point in each region.

4.2.4 Animal condition assessment and blood metabolic profiles

A total of three hundred and sixty (360) sheep were randomly selected from the study area during the hot-dry period and the following information was collected; sex, age, body weight, body condition score (BCS) and metabolites profiles.

Animal age was determined by examining their dentition following the method outlined by Turton (1999). The animals were then classified into three categories: weaners (0 teeth/no permanent incisors), yearlings (2 teeth/2 permanent teeth), and adults (≥ 4 teeth/4 permanent teeth). Body weights were estimated from heart girth measurements taken by using weighing band (Afrivet Training Services), according to de Villiers *et al*. (2009) and Asefa *et al*. (2017) while BCS was estimated using a scale of 1 – 5, with 1 being very thin and 5 being very fat as described by Kenyon *et al*. (2014) and Mvinjelwa *et al*. (2014).

Blood samples were collected from sheep by venipuncture (jugular vein) into 10ml vacutainer tube (plain clot activator) and put on ice (cool box). After separation of serum from clot by centrifugation at 3000 rpm for fifteen (15) minutes, the serum samples were transferred into 4 ml vacutainer tubes (plain clot activator) then frozen at -20 ^{o}C until analysis. The chemistry profile of serum samples (glucose, blood urea nitrogen, creatinine, globulin, albumin, total protein, calcium, phosphorus, cholesterol and total bilirubin) plus enzymes activity (gammaglutamyltranseferase and alkaline phosphatase) were determined using IDEXX Catalyst Dx® Chemistry Analyzer (IDEXX Laboratories Inc 2014, Westbrook, ME, USA).

4.2.5 Statistical Analysis

Data on rangeland conditions (herbaceous biomass yield, chemical composition and density and cover percentage of woody plants) and animal condition (live body weights, BCS and concentration of blood metabolites) were analysed using one-way analysis of variance (SAS ,2013) for Completely Randomized Design (CRD). The following model was used:

$$Y_{ij} = \mu + T_i + E_{ij}$$

Yij = response variables (1, 2, 3, 4, 5, 6 and 7)

> 1 - Herbaceous biomass yield; 2- Chemical composition (dry matter, crude protein, neutral detergent fibre, acid detergent fibre, acid detergent lignin, calcium and phosphorus); 3 - density of woody plants; 4 - cover percentage of woody plants; 5 - live body weights; 6 – body condition score; 7 - concentration of blood metabolites (creatinine, urea, total protein, albumin, globulin, total bilirubin, calcium, phosphorus, glucose, cholesterol, alkaline phosphatase and gamma glutamyltransferase),

μ = overall mean

T_i = effects of sampling point (district and distance from watering source) or animal factors (age and physiological stage)

and E_{ij} = random error.

Means were separated using the Tukey's procedure and statistical significance was declared at $P \leq 0.05$.

4.3 RESULTS

4.3.1 Rangeland condition

Herbaceous (grasses and forbes) biomass yields from the investigated districts were different (P<0.0001) and had an average biomass yield of 1017.00 kg/ha. Statistically, the highest and lowest biomass yields were found in the Southern district (2360 kg/ha) and the South East district (221.28 kg/ha) respectively (Figure 4.3). The Kgatleng district had the second highest biomass yield (1211.07 kg/ha) while the Kweneng district has statistically similar biomass yield to the South East district. The study also found that the herbaceous biomass yield was influenced (P<0.05) by the distance of grazing point from the main water sources across all districts. On average, the furthest grazing point (3km) produced the highest herbaceous biomass yield (1360 kg/ha), while the nearest grazing point (0.5 km) to watering point had the lowest biomass yield (712.93 kg/ha).

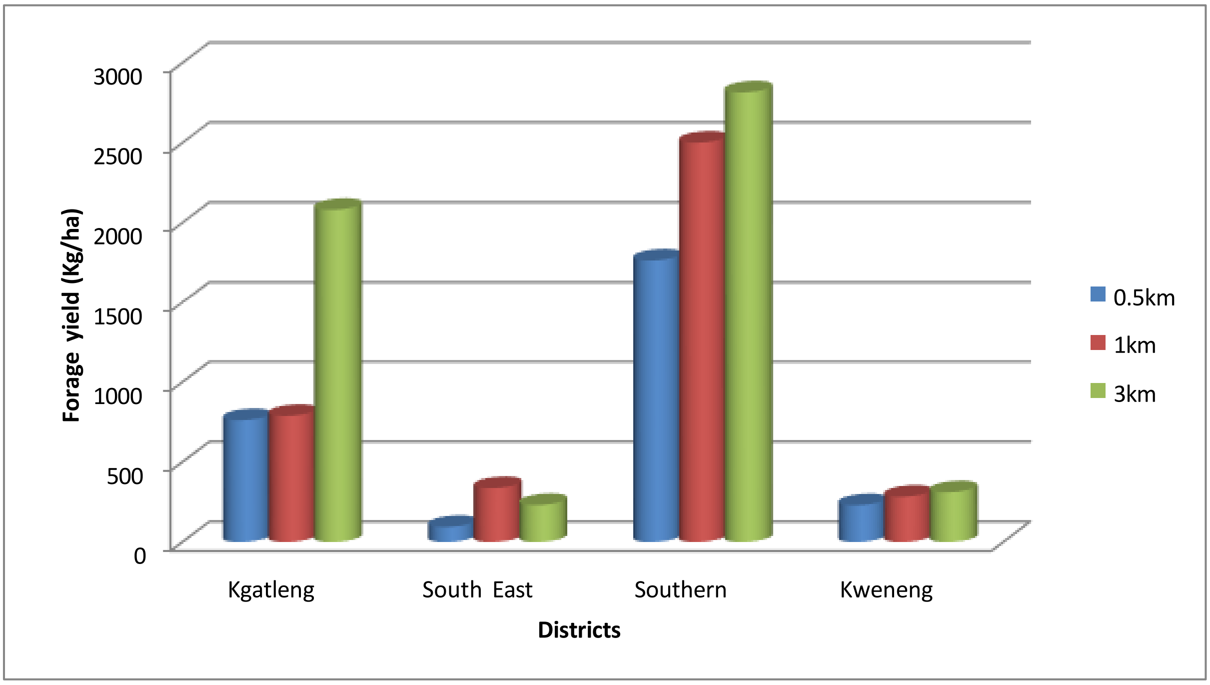

Figure 4. 2 Herbaceous biomass yield from different grazing points away from watering points during late autumn-early winter period

Table 4.2 shows the chemical composition of herbaceous forage from communal rangelands in south-eastern regions of Botswana. It was established that forage from the districts had similar (P>0.05) DM content and different (P<0.001) crude protein (CP) levels. Higher (P<0.05) CP levels were found in forages from the Kgatleng (6.06%) and South East (6.07%) districts than from the Southern (4.40%) and Kweneng (3.54%) districts. Inversely, forages from the Southern district had a significantly higher content of neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) than those from the South East district. It was also found that forages from the Kgatleng district had a higher (P<0.05) calcium content than those from the South East (13.07 ppm), Southern (13.03ppm) and Kweneng (12.53 ppm) districts. However, herbaceous forages from the South East and Southern districts had statistically higher phosphorus levels than those from the Kweneng districts. It was also observed that grazing distance had an influence (P<0.05) on the amount of CP, NDF, ADF, Ca and P in forages. On average, herbage from (0.5 km) grazing points closest to the watering points had the highest (P<0.05) levels of CP (5.79%) and Ca (16.81 ppm) and lowest levels of NDF (57.68%), ADF (36.61%) and P (9.40 ppm). Conversely, forages from the furthest (3 km) grazing points had statistically lowest levels of CP (4.46%), Ca (10.68 ppm) and P (9.40 ppm) and highest (P<0.05) levels of NDF (60.87%) and ADF (37.74%).

Table 4.2 Chemical composition of herbaceous plants from different districts found in Gaborone and Southern regions during late autum-early winter period

Districts	Point	DM	CP	NDF	ADF	ADL	Ca	P
	Km			%			ppm	
Kgatleng								
	0.5	70.10^{cd}	7.63^{a}	49.26^{d}	35.29^{c}	29.58^{bc}	20.30^{a}	11.60^{a}
	1.0	71.74^{bcd}	5.62^{c}	56.84^{cd}	36.98^{bc}	32.75^{abc}	12.63^{def}	10.08^{b}
	3.0	80.29^{ab}	4.92^{de}	68.97^{ab}	44.10^{a}	40.07^{a}	11.52^{defg}	7.77^{de}
South East								
	0.5	81.77^{a}	6.94^{b}	55.00^{cd}	33.65^{c}	26.00^{c}	15.39^{c}	11.73^{a}
	1.0	70.05^{cd}	5.55^{cd}	54.59^{cd}	31.74^{c}	26.80^{c}	13.06^{de}	12.03^{a}
	3.0	71.51^{bcd}	5.73^{c}	58.18^{cd}	32.74^{c}	27.77^{c}	10.76^{fg}	8.51^{cde}
Southern								
	0.5	78.33^{abc}	6.44^{b}	72.54^{a}	43.35^{ab}	39.89^{a}	17.91^{b}	9.15^{bcd}
	1.0	76.47^{abcd}	3.28^{h}	70.55^{ab}	42.62^{ab}	36.54^{ab}	11.23^{efg}	9.68^{bc}
	3.0	72.88^{abcd}	3.56^{gh}	69.19^{ab}	42.35^{ab}	35.97^{ab}	9.94^{g}	12.51^{a}
Kweneng								
	0.5	75.34^{abcd}	2.15^{i}	53.91^{cd}	34.17^{c}	25.82^{c}	13.63^{cd}	7.35^{e}
	1.0	67.75^{d}	4.43^{ef}	60.64^{bc}	38.44^{abc}	27.42^{c}	13.45^{cde}	9.19^{bcd}
	3.0	71.35^{bcd}	4.03^{fg}	60.75^{bc}	37.39^{abc}	29.87^{bc}	10.51^{fg}	8.80^{bcde}
	Means	73.96	5.02	60.87	34.74	31.46	13.36	9.87
	s.e.m.	3.51	0.22	3.46	2.63	2.73	0.77	0.50
	P-value	0.0909	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

DM = dry matter, CP = crude protein, NDF = neutral detergent fibre, ADF = acid detergent fibre, ADL = acid detergent fibre, Ca = calcium, P = phosphorus.

^{a,b,c,d,e,f,g,h,i} Means within a column with different superscripts differ ($P<0.05$)

Similar woody plants densities (P>0.05) were observed between the investigated districts in this research and the average woody plants density in this work was 1095.84 units/ha (Table 4.3). An inverse relationship was noted between herbaceous biomass yield and cover percentages of woody plants in this research. Table 4.3 further indicates that cover percentages of woody plants in all districts were statistically different (P < 0.05) and the average cover percentage was 69.20 %. The Southern District had the lowest cover percentage of woody plants when compared to other districts.

Table 4.3 Density and cover percentage of woody plants in Southern and Gaborone regions during dry winter- spring period

District	Density (units/ha)	Log Density	Cover (%)
Kgatleng	1100.00 ± 419.60	6.87 ± 0.35	75.18^{a} ±11.25
South East	1500.00 ± 302.81	7.30 ± 0.22	93.25^{a} ±1.23
Southern	655.57 ± 204.99	6.35 ± 0.40	37.75^{b} ±8.23
Kweneng	1077.78 ± 147.64	6.96 ± 0.15	70.63^{a} ±7.68
Means	1095.84	6.87	69.20
CV (%)	45.51	7.55	19.97
P-value	0.2620	0.2365	0.0074

*ab- Means with different superscripts in a column are significantly different (P < 0.05)

4.3.2 Animal conditions and blood profiles

The results indicated that the live body weights of all sheep were not significantly affected by the district, except for adult ewes (Table 4.4). Adult ewes, both pregnant and suckling, from the Southern district had significantly (P<0.05) higher body weights than those from the South East and Kweneng districts. It was also found that the body weights of adult sheep were statistically influenced by their physiological status, higher (P<0.05) body weights were observed in adult rams (60.13 kg) and pregnant ewes (43.20 kg) than adult castrates (52.70 kg) and suckling ewes (38.48 kg) respectively. The mean BCS of sheep in this work was influenced (P<0.05) by districts. Sheep from the Kgatleng district had the statistically higher (P<0.05) mean BCS than that from the South East district (Figure 4.4). Furthermore, yearling castrates and suckling ewes in the Kweneng district as well as adult pregnant ewes in the Southern district had higher (P<0.05) BCS than their counterparts in the South East. It was also found that suckling ewes and rams had the lowest and highest BCS respectively.

Table 4.4 Live-weights (kg) of different stages of sheep in Gaborone and Southern regions during late winter-early spring period

District	Weaners		Yearlings				Adults				Means
	Male	Female	Ram	Castrate	Pregnant	Suckling	Rams	Castrates	Pregnant	Suckling	
Kgatleng	31.11	30.00	50.06	41.22	39.22	34.61	60.83	54.94	45.11 ^{ab}	38.67^{ab}	40.57
South East	28.22	28.00	39.33	38.56	36.61	32.39	59.17	48.22	40.39^{b}	36.67^{b}	37.15
Southern	33.55	30.34	38.96	39.22	36.37	37.78	59.89	54.00	48.55^{a}	43.44^{a}	40.09
Kweneng	33.11	31.33	43.00	42.50	35.44	32.56	63.1	55.33	39.78^{b}	35.56^{b}	36.68
s.e.m	3.30	2.43	3.97	2.53	1.85	4.08	5.57	6.16	2.66	2.03	3.02

*^{ab} - Means with different superscripts in a column are significantly different (P<0.05)

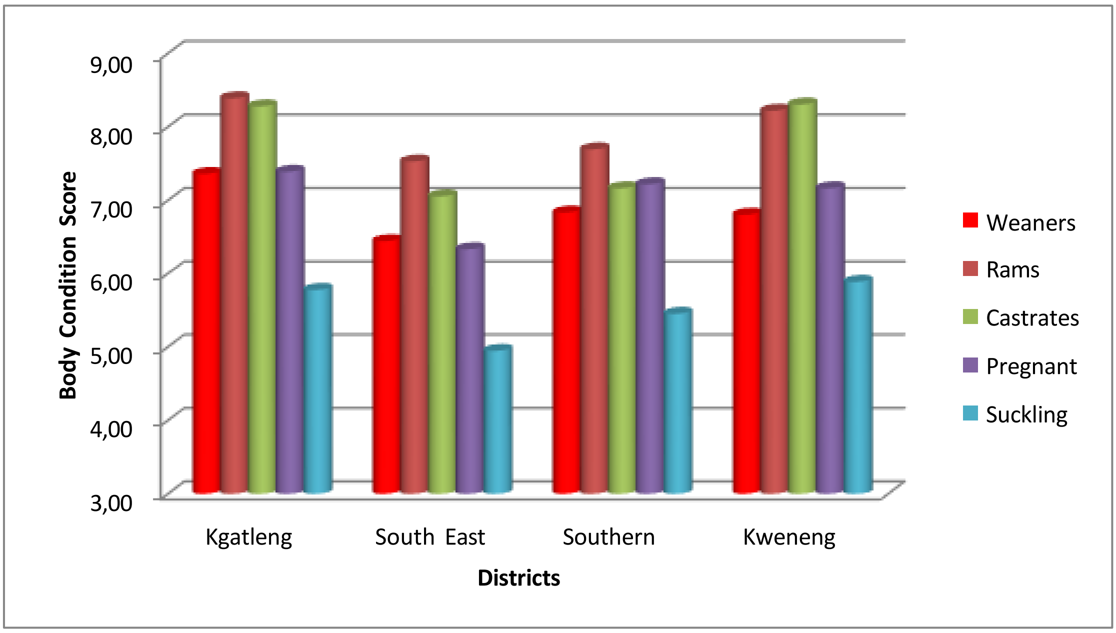

Figure 4. 3 Body condition scores of sheep under different physiological stages during late winter-early spring period

Table 4.5 shows that the concentrations of blood metabolites of grazing sheep were significantly different (*P*<0.05) between the districts except albumin and phosphorus. The results (Table 4.5) also indicate that all blood metabolites were within their normal ranges except those of globulin, which were higher than normal range. Furthermore, sheep from the Kgatleng and Southern districts had lower (*P*<0.05) concentrations of creatinine than those from the South East and Kweneng districts. In addition, sheep from the former districts had significantly lower blood urea nitrogen (BUN) than those from the South East district. Significantly lower (*P*<0.05) levels of globulin and total protein were observed in sheep from the Kgatleng and Kweneng districts than those from the Southern district. Furthermore, this research found the highest and lowest levels (*P*<0.05) of total bilirubin and calcium in sheep from the Southern district and the Kweneng and South East districts respectively.

The levels of glucose, cholesterol, alkaline phosphatase (Alkp) and gamma glutamyltransferase (GGT) of grazing sheep in the current study were influenced (*P*<0.05) by districts (Table 4.6). The results also indicated that communal sheep from the Southern district had significantly (*P*<0.05) lower levels of glucose and higher levels of alkaline phosphatase. On other hand, sheep from the South East had a higher (*P*<0.05) concentration of cholesterol than those from other districts while those from the Kgatleng and Kweneng districts had significantly higher levels of gamma glutylaminotransferase (GGT) than those from the other two districts.

Table 4.5 Concentrations of blood metabolites related to protein and minerals metabolism in sheep raised on communal rangelands in SE regions during dry winter -spring period

District	Protein metabolites						Minerals	
	Creatinine (mmol/l)	Urea (mmol/l)	Total Protein (g/l)	Albumin (g/l)	Globulin (g/l)	T/bilirubin (micrmol/l)	Calcium (mmol/l)	Phosphorus (mmol/l)
Kgatleng	52.82^{b}	4.74^{b}	69.16^{b}	24.67	44.47^{bc}	4.51^{ab}	2.31^{ab}	1.76
South East	62.96^{a}	5.72^{a}	70.42^{ab}	24.54	45.84^{ab}	4.46^{ab}	2.28^{b}	1.94
Southern	56.01^{b}	4.98^{b}	72.08^{a}	25.24	46.94^{a}	5.08^{a}	2.37^{a}	1.78
Kweneng	63.98^{a}	5.40^{ab}	68.61^{b}	24.53	44.04^{c}	4.25^{b}	2.27^{b}	1.78
s.e.m	1.87	0.24	0.76	0.40	0.59	0.24	0.03	0.73
Ref. range	53 – 133	1.8 - 7.1	56 - 78	24 - 37	32 - 41	1.7 - 6.8	2.28 - 2.70	1.3 - 2.9

BUN - Blood Urea Nitrogen; micrmol/l - micromole per litre; mmol/l - millimole per litre; g/l -grams per litre; Ref. range - reference range (as adopted from IDEXX laboratories, 2014)

*abc - Means with different superscripts within a column are significantly different (*P*<0.05

Table 4.6 Energetic profile and enzymatic activities of sheep raised on communal rangelands in SE regions of Botswana during dry winter -spring period

Districts	Energetic profiles		Enzymatic Activities	
	Glucose (mmol/l)	Cholesterol (mmol/l)	ALKP (U/l)	GGT (U/l)
Kgatleng	1.37^{a}	1.04^{b}	104.08^{b}	60.37^{a}
South East	1.39^{a}	1.41^{a}	90.98^{b}	47.12^{b}
Southern	1.16^{b}	1.14^{b}	131.0^{a}	44.02^{b}
Kweneng	1.45^{a}	1.07^{b}	98.25^{b}	66.29^{a}
s.e.m	0.06	0.07	8.19	3.26
Ref. range	2.78 - 4.45	1.14 - 2.12	50 - 228	33 -55

GGT – Gamma glutamyltransferase; ALKP - Alkaline Phosphatase; Ref. range - reference range (as adopted from IDEXX laboratories, 2014)

$*^{ab}$ - Means with different superscripts within a column are significantly different (P<0.05)

4.4 DISCUSSION

4.4.1 Herbaceous Biomass Yield and Nutritional Analysis

Observations from the study showed higher herbaceous biomass yield in the Southern district than in the South East district. This could be due to their differences in cover percentage of woody plants. In previous studies, bush encroachment, carrying capacity and animal density were identified as some of factors that may influence herbaceous yield (Abule *et al*., 2005; Nsinamwa *et al*., 2005). In addition, the differences in the type and maturity of grasses between these districts could have also contributed to the variation in their biomass yield. It was noted that a large part of the Southern district was dominated by perennial grasses like *Stipagrostis, Aristida* and *Eragrostis species* while the South East district was occupied largely by annual grasses and forbs. These grasses, *Aristida* and *Stipagrostis* species are classified as poor species since they contain high fibre and low protein levels (Mpinyane *et al*., 2015) and have high stalk percentage during winter and thus poorly digested by animals during dry seasons. Hence, farmers in the Southern district were urged to feed protein and energy supplements like oilseed cakes to improve forage digestibility and performance of grazing animals. In communal rangelands situated around peri-urban regions like Tlokweng and Ramotswa villages within the South East district, overgrazing could potentially be attributed to several factors. These include the constraints of limited grazing areas and diminished carrying capacity due to elevated stocking densities, the expansion of agricultural projects encroaching upon grazing lands, and the accelerated pace of urbanization in the area (Talbot, 1986; Moleele & Mainah, 2003; Tripathi & Rani, 2017). In addition to being the smallest district in Botswana (Figure 3.1) and densely populated (Statistics Botswana, 2018), the carrying capacity of communal grazing areas in the South East district were observed to be greatly affected by soil erosion as well as high density of commercial farms. Nevertheless, the famers in this district had greater access to crop residues that could be used to improve feed supply to their animals.

When evaluating the relationship between herbaceous forage yield and grazing distance from main water sources, the results from this study show that the highest biomass was obtained in grazing areas that were furthest from main water source point. The findings are in agreement with studies by Mugabe *et al*. (2017) locally and Malek *et al*. (2019) in Ethiopia. In most cases, this situation was attributed to the intensity of grazing pressure and heavy trampling of the grazing area by animals as they access the drinking water (Mugabe *et al*., 2017; Malek *et al*., 2019). According to Malek *et al*. (2019), such high grazing pressure negatively affected the occurrence and growth of highly palatable grasses and encourage increased proliferation of undesirable and grazing tolerant grasses in areas near to watering point. This may lead to insufficient feed intake and poor growth in farm animals that cannot travel long distances to graze especially lambs and old or unfit sheep. Ultimately, this may result in the need for high rates of supplementary feeding and high feeding costs amongst farmers who have their kraals within such a distance.

The CP content of herbaceous forage in the present work was below the recommended 70g/kg DM CP requirement for mature ruminant, as established by Van Soest (1994). Hence, supplementing with protein concentrates could be critical amongst cattle and small stock in the investigated rangelands. The inverse relationship between nutrient level (CP and Ca) of herbaceous forage and the distance from water source in this study (Table 4.2) was also found by Nsinamwa *et al*. (2005) in Botswana and Malek *et al*. (2019) in Ethiopia. This trend could be primarily attributed to soil fertility. Studies conducted by Moleele and Perkins (1998) and Nsinamwa *et al*. (2005) suggested that the high nitrogen content of soils closest to watering points is largely influenced by the high concentration of dung and urine. Consequently, this results in higher crude protein (CP) levels in forages situated close to watering points. Furthermore, dominance of forbs around the water source point could also have increased the overall CP content of herbaceous layer in close to such point. Generally, forbs can resist heavy trampling and contain higher levels of CP and minerals compared to grasses (Mpinyane *et al*., 2015). Contrary to Nsinamwa *et al*. (2005) who observed that high fibre contents in herbaceous forage close to watering point, this study found high levels of NDF and ADF contents in forages that were furthest from watering point. This may be associated with dominance of mature grasses very far from main watering point. It has been found that age or growth stage of plants increases the amount of crude fibre (Van Soest, 1982).

4.4.2 Density and Canopy cover of woody plants

The mean density of woody species in this work was less than 2500 units/ha, a threshold that indicates that an area is bush encroached (Dalle *et al*., 2006; Makhabu *et al*., 2019), hence the region investigated may not be classified as bush encroached. However, the study found a contrasting mean density of woody species to Mugabe *et al*. (2019) and Makabu *et al*. (2019), who found 930 units/ha and 2035units/ha in communal grazing areas in Gaborone North (South East district) and Molepolole village (Kweneng district) respectively, even though these studies were done in same region as this one. One of the major reasons for this variation is the spatial difference in time between these studies. Also, the density of woody species in the current study was very low compared to 4785 units/ha found by Teketay *et al*. (2016) in Nature Reserve in the South East district and this large disparity may be due to differences in animal species and densities plus diet (plant) preferences. Other factors related to anthropological activities such as timber/wood harvesting and stocking rates as well as characteristics of woody species between these studies may have also contributed to density differences, as observed in studies by Madubansi and Shackleton (2007) and Twine and Holdo (2016). On the other hand, this study agrees with Makabu *et al*. (2019) and Teketay *et al*. (2016) that *Dichrostachys ceneria* was most dominant woody species in the south-eastern part of Botswana. Although this dominance might lead to its potential invasiveness and subsequent reduction of herbaceous species (Mudzengi *et al*., 2014), it also shows great potential in improving livestock feed supply and animal nutrition during dry season (Mthiyane *et al*., 2019), especially when their pods are collected and utilized for animal feeding. The pods are a good source of protein and could replace expensive commercial protein supplements in small ruminants kept by resource-poor farmers (Mlambo *et al*., 2002). Marius *et al*. (2018) and Choongo *et al*. (2008) also indicated that supplementing ruminants with pods improved their feed intake and weight gains and reduced ciliate protozoa in the rumen.

Even though woody plant density in this work indicated that the area investigated was not bush encroached, the percentage woody plant cover indicated otherwise. The mean percentage of woody plant cover in this study (69.20%) was higher than 40% that is considered equilibrium between encroached and non-encroached (Dalle *et al*., 2006). Therefore, Table 4.3 shows that the Southern district remained unencroached. This phenomenon could potentially be linked to the district's history of frequent veld fires, which might have contributed to its preservation. The current findings were also in agreement with findings by various authors (Moleele & Perkins, 1998; Teketay *et al*., 2016; Makabu *et al*., 2019) that *D. cinerea* and *Acacia* species are the dominant encroachers in south eastern part of this country. Woody plants that are protected by thorns are not easily browsed by sheep and cattle and hence these animals rely mostly on pods of these plants. It should be noted that there are several factors that could have led to differences in woody cover between the Southern and other districts in this study. Some of these factors include topography and soil fertility (Moleele & Perkins, 1998), plant structure or height (Twine *et al*., 2016), herbivory and fire regimes (Mograbi *et al*., 2015) as well as frequency of wood cutting for firewood and construction materials (Wessels *et al*., 2011). In addition to edaphic factors, rainfall patterns and nutrient availability plus water infiltration gradients can also influence woody vegetation structure and cover (Ringrose *et al*., 2002). Contrary to findings by Kgosikoma *et al*. (2012) that found a negative relationship between clay content and woody plant cover, the present study found significantly high woody plant cover in districts that have soils with high clay content (hardveld).

4.4.3 Live-weights of sheep raised on rangelands

Sheep relying on natural grazing for feed tend to mobilize their body reserves during periods of feed shortage; hence body condition assessment is a simple and reliable way to evaluate nutritional status of grazing sheep periodically (Sezenler *et al*., 2011). Animal condition assessment often assists farmers in developing appropriate strategies for the provision of nutritional support during periods of reduced feed abundance. Animal condition assessment tools include weighing and body condition scoring of live animals and assessment of some blood metabolites associated with nutrient sufficiency (Ndlovu *et al*., 2007). Live weight and body condition scores of a mature sheep are good indicators of energy and protein sufficiency (Brown *et al*., 2015).

The current findings reveal higher live weights of adult ewes in the Southern district than that in the South East and Kweneng districts; this may be attributed to its significantly high herbaceous forage supply. Hence, adult ewes in the Southern district had a higher possibility of increased DM and total nutrients intakes compared to their counterparts in other districts, hence improved their body weight gains. Again, the level of dietary fibre in forage material in the Southern district may have created optimum rumen condition for microbes to digest feed.

Lu *et al*. (2005) pointed that adequate salivation creates optimal rumen pH for cellulolytic ruminal microbes, resulting in sufficient fibre digestion and improved synthesis of microbial protein and volatile fatty acids (VFAs) in the rumen. Increased production of microbial protein and VFAs in the rumen tends to be associated with improved body weight gains and feed efficiency in ruminants (Garg, 1998; Jasim *et al*., 2015; Harun & Sali, 2019). On the other hand, low dietary fibre in forages in the South East and Kweneng districts may have resulted in faster passage rate time and shorter retention time for rumen microbes in adult ewes, which might have affected their ability to thoroughly digest the consumed feed. Consequently, this situation could have contributed to reduced microbial protein production and lower levels of VFAs. Conversely, using live weight as a management tool also presents certain drawbacks. For example, it necessitates the use of expensive equipment for weighing the animals and there are limitations in its ability to accurately reflect animal body condition and overall well-being (Kenyon *et al*., 2014). The previous authors also noted that a particular live weight could indicate a poor condition and good condition in a large framed and small framed animal respectively. Despite these, various authors (Sezenler *et al*., 2011; Mvinjelwa *et al*., 2014; Kenyon *et al*., 2014) found a strong positive relationship between live weight and body condition score in sheep.

4.4.4 Body Condition Score

The body condition scores (BCS) of communal sheep in the present work ranged from 2.60 to 4.10, suggesting that they were averagely well fed (Thompson & Meyer, 1994). Since the investigated area had low herbaceous yield and potentially low nutrients supply, the good BCS of sheep could be a result of high intake of nutritious and palatable pods of *Acacia species* and *Dichrostachys ceneria*; dominant woody plants. Also, the good BCS obtained during dry seasons, commonly characterised by high dietary restriction (due low and poor feed supply), may suggest that sheep investigated were adapted to high fibre diet and had reduced seasonal weight loss, something that may be influenced by the certain traits of a dominant sheep breed (Tswana sheep) kept by local smallholder farmers. The breed is classified as fat tailed (Nsoso *et al*., 2004); a class is known for its reduced body weight loss during periods of undernutrition (Atti *et al*., 2004; Alves *et al*., 2013), hence has a high potential to maintain good BCS during low feed periods.

The present findings indicated that BCS of sheep in Kgatleng were significantly above that in the Southern districts. Since these previously mentioned districts had similar average nutritional profile, the differences in BCS of sheep may be associated with variation in herbaceous forage supply a scenario that might have affected the total amount of ingested nutrients received by animals for growth and fat deposition. Hence, low BCS of sheep in the South East district could indicate that nutrients supply was limiting from rangelands, hence the animals were on negative energy balance. This scenario often leads to elevated rates of mobilization and utilization of stored body fats and protein reserves, as the animal attempts to provide amino acids for protein synthesis and sources of carbon for gluconeogenesis (Kenyon *et al*., 2014; Nechifor *et al*., 2022). To improve feed supply and poor BCS in communal sheep in South East, various authors (Syomiti *et al*., 2011; Abera *et al*., 2018; Nechifor *et al*., 2022) have urged smallholder farmers to supplement their animals with processed and fortified crop residues-based diets, especially during critical periods of their production cycle.

Since ewes with BCS of 3.0 had been reported to have high fertility rate, lambing rate, litter size (Thompson & Meyer, 1994; Sejian *et al*., 2009; Aliyari *et al*. (2012), a similar statement could be said about ewes (BCS 3.11) in this study. Similar BCS was observed by Mvinjelwa *et al*. (2014) in crossbred woollen ewes raised on rangelands of Eastern Cape Province in South Africa. However, the BCS of ewes in this current study was higher than those observed in Sudan desert sheep and Sakiz and Gokceada indigenous sheep breeds in Turkey grazing on communal rangelands by Idris *et al*. (2011) and Sezenler *et al*. (2011) respectively. It was also observed that castrates and rams had higher BCS than suckling ewes (Figure 4.4) across all the districts and such difference could be related to their physiological status. In most cases, after parturition, suckling ewes tend to have low feed intake, negative energy balance and fast mobilization of body reserves (Simeos *et al*., 2021) resulting in drastic weight loss and low BCS in suckling ewes. Furthermore, Idris *et al*. (2011) reported that low BCS in suckling ewes could be due to lack of supplementation in late gestation with concentrates to support ewe maintenance, foetal growth, mammary development plus colostrum and milk production.

4.4.5 Serum Biochemistry

Ndlovu *et al*. (2007) reported that even though it is easier and cheaper to determine body weight and BCS of animal when evaluating its nutritional status, such approaches have some limitations that can be complemented by use of blood metabolites and haematology. Several studies have reported that nutritional deficiencies, reproductive status as well as health status of animals can be detected more precisely by evaluation of their blood metabolites (Otto *et al*., 2000; Pambu-Gollah *et al*., 2000; Ndlovu *et al*., 2007; Nawito *et al*., 2015). The current findings of high creatinine levels in sheep with low body weights in the South East and Kweneng districts were not expected since such concentrations of creatinine are mostly associated with high body weight and muscle mass in animals (Ndlovu *et al*., 2007; Chikwanda & Muchenje, 2017). Conversely, the current trend of high creatinine concentration in ruminants under restricted nutrition was consistent with the findings by Keogh *et al*. (2015) in Holstein-Friesian bulls during restricted feeding. Again, significantly higher creatinine concentrations were also observed in heifers (Whittet *et al*., 2019) and goats' kids (Zhu *et al*., 2020) that were fed low protein diets compared to those diets with higher protein contents. High creatinine in poor conditioned ruminants in this work may be ascribed to intense mobilization of muscle protein for energy demand (Pires *et al*., 2013) to sustain long walking distances in rangelands in search of feed (Otto *et al*., 2000).

The present findings on BUN concentrations also further suggest the possibility of sufficient feed intake in communal sheep in SE regions. The observed high concentration of BUN observed in sheep grazing in communal rangelands in the South East district, with low feed supply, was not expected. Under normal conditions, high BUN in ruminants is correlated to high intake of CP (Caldeira *et al*., 2007). However, a possibility for high intake of CP in this work is minimal due to low herbaceous biomass supply in the South East district and high chances of low nutrients intake by its sheep. Therefore, the elevated BUN in poor conditioned sheep in the South East district may result from increased breakdown of endogenous protein or muscles for energy production, according to the works by Ndlovu *et al*. (2007) and Rumosa-Gwaze *et al*. (2010). Increased levels of BUN and creatinine in sheep under feed restriction were also observed by Abdalla *et al*. (2014), who linked this trend to high urea nitrogen recycling efficiency during adaptation to feed scarcity. Studies by Saro *et al*. (2020) and Paula *et al*. (2013) reported the dominance of albumin amongst the major circulating proteins and inferred that its level tends to accurately estimate the immediate dietary protein intake and nutrient supply. Even though the current concentrations of albumin were within the normal range for sheep (24 - 37 g/l), they were on the lowest levels. This further concurs with the statements that associated elevated concentrations of protein metabolites (creatinine and BUN) with the possibility of low protein intake amongst sheep in this study. Also, the present study revealed that total protein (TP) and globulin had direct relationship and globulin concentrations were above the normal range for sheep. Since the study was done during hot and dry seasons, the observed above normal levels of TP may reflect the low hydration status of animals studied (Counch *et al*., 2017). Significant difference between the concentrations of TP and globulin in the Southern district (highest) and the Kgatleng and Kweneng districts (lowest) may be attributed to variations in length of feed scarcity and protein deficiency (Caldeira *et al.*, 2007; Afroz *et al*., 2020) and production levels of immunoglobulins caused by longer exposure to endoparasitic infections (Otto *et al*., 2000; Chovanova *et al*., 2021). Again, since increased total bilirubin levels has been observed in sheep with endoparasite infections (Cinar *et al*. 2018), elevated levels of total bilirubin in sheep from the Southern district may suggest high internal parasites infestation. Furthermore, it was observed that the concentration of calcium and herbaceous feed supply in this study were positively correlated and probably with total dry nutrient intake. This was consistent with the findings by Saro *et al*. (2020) who noted lowest calcium concentration in Asaaf sheep fed low protein diets (13.4% CP) compared to that fed high protein diets (17.3% CP). Direct relationship between calcium concentration and amount of protein in blood serum is mainly due to high amount of calcium bound to plasma proteins, mainly albumin (Merck Manual, 2015). Low Ca levels in the current study may indicate asymptomatic hypocalcaemia or low critical calcium values in the research sheep.

The current investigation also revealed that communal sheep had below normal glucose concentrations. This tendency is consistent with the findings by Grunwaldt *et al*. (2005) in cattle raised on rangeland. These authors associated decline in glucose concentrations to significant decline in feed consumption, increase in respiratory activity during hot and dry conditions and probably due to long walking distances in search for feed. The present results further showed significantly lower blood glucose concentrations in the Southern district than other districts. According to the findings by Pambu-Gollah *et al*. (2000) and Reynolds *et al*. (2003), elevated blood glucose in sheep raised in the Kgatleng, South East and Kweneg districts corroborates the previous results that suggested that these districts had inadequate feed supply, resulting in insufficient energy intake to satisfy glucose requirements and hence increased rate of gluconeogenesis. A significantly high concentration of cholesterol for communal sheep in the district (South East) with lowest feed restriction was in accordance with their relatively lowest BCS and further suggested that sheep in the South East district had increased mobilization of body adipose tissue to provide energy, possibly due to high decreasing rates of dietary energy intake and depleted glucose precursor reserves (Pambu-Gollah *et al*., 2000; Tadese *et al*., 2021). This finding agreed with Abdalla *et al*., (2014), who reported increased level of serum total lipids and cholesterol in Barki sheep (a fat-tailed sheep like Tswana sheep) under restricted feeding in semi-arid conditions and attributed this to high catabolism of fat deposited in its tail.

Even though the concentrations of alkaline phosphotase (AKLP) in this study were within the normal range, their low values (close to the lower limit) may suggest decreasing nutrients intake and health status amongst the studied animals (Sharma *et al*., 2014). The current positive correlation between AKLP and Ca concentrations shows their close association in the process of bone mineralization (calcification), according to various authors (Toba *et al*., 1992; Wolkers *et al*., 1994; Ansari *et al*., 2022). Reduced (P<0.05) levels of ALKP in communal sheep raised in the South East and Kweneng districts were consistent with the findings by Wolkers *et al*. (1994) on the effects of long-term undernutrition in red deers. GGT is mainly produced from the liver (Couch *et al*., 2017) and its concentration is highly related to optimal liver function (Souza *et al*., 2020). The findings of this study showed higher concentrations of GGT in communal sheep from the Kgatleng and Kweneng districts than other districts. Increased GGT levels in sheep may be associated with their increased hepatic metabolism (Antunovic *et al*., 2011), mostly due to liver disorders caused by chronic liver helmithiosis and restricted feeding (Rumoza-Gwaze *et al*., 2012; Hernandez *et al*., 2020). In addition, the current findings on GGT concentration corroborates the previous results in this study that suspected low nutrients intake and negative energy balance in communal sheep raised in the Kweneng district, this scenario tends to induce high transamination activity, when large pool of amino acids are used for gluconeogenesis (Cabiddu *et al*., 2020).

4.5 Conclusion

It is concluded that most districts in this study were bush-encroached and their herbaceous forage had low biomass and CP content plus high fibre values. The results of this work also show that herbaceous yield, NDF and ADF levels were directly affected by grazing distance from the main water source. Furthermore, significantly lowest feed supply in the South East district may have resulted in lowest total nutrients intake by its sheep and hence their lowest live weights and BCS in this study. Observed high concentrations of creatinine, BUN, glucose and cholesterol for communal sheep in the South East district illustrate intense mobilization of protein and energy from body reserves, a situation associated with extended feed scarcity and inadequate nutrients intake by the animal. The findings of this study also illustrate the importance of supplementary feeding, particularly with oilseed meals, molasses and minerals, to circumvent deficiencies of protein, energy and minerals in grazing sheep during hot dry seasons.

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CHAPTER 5.0 NUTRIENTS DIGESTIBILITY, GROWTH PERFORMANCE AND NITROGEN UTILISATION OF TSWANA LAMBS FED DIETS CONTAINING DIFFERENT LEVELS OF CANOLA AND SUNFLOWER SEED CAKE

Abstract

Inadequate nutrition and poor performance of animals raised on communal rangelands can be improved by utilization of oilseed meals in animal feeding systems. Soybean meal (SBM), the most dominant protein source in animal diets, is not affordable to most smallholder farmers due to its high costs. Therefore, this study investigated the effects of the inclusion of canola meal (CM) and sunflower seed cake (SSC) as alternative protein sources to SBM in lamb diets on nutrient intake and digestibility, growth performance, nitrogen utilisation and blood metabolites. For this purpose, 36 six-months old, castrated lambs were randomly allocated to nine (9) isonitrogenous diets in a completely randomized design (CRD), with four (4) animals per treatment as replicates. The SBM in experimental diets was substituted by CM or SSC at 0 (Control), 25 (CM25/SSC25), 50 (CM50/SSC50), 75 (CM75/SSC75) and 100% DM (CM100/SSC100) inclusion levels and the best inclusion levels of CM and SSC were also determined. It was observed that nutrient intakes and in-vivo digestibility of diets were influenced ($P<0.05$) by the inclusion of CM and SSC in diets. Higher intakes of dry matter (DM) and organic matter (OM) were observed in lambs that consumed diets SSC75 and CM75. Diet SSC75 produced highest ($P<0.05$) intakes of gross energy (GE) and crude protein (CP). On the other hand, all inclusion levels of CM and SFM produced similar effects ($P>0.05$) on digestibility of diets. Diet also significantly influenced weight gains of lambs but did not affect their final weight, feed conversion rate (FCR), body condition scores (BCS) and nitrogen utilization parameters. Though CM and SSC influenced all investigated parameters similarly,

CM tended to produce superior values of growth performance in lambs. In addition, replacing SBM with CM and SSC in growing diets of lambs did not affect most of the blood metabolites related to protein (except urea) and energy profile. In conclusion, SBM can be partially or totally replaced by CM and SFM in the diets of growing lambs without alterations to nutrient intakes and digestibility, growth performance, nitrogen balance and blood metabolites.

5.1 Introduction

Locally, the indigenous sheep, Tswana breed, dominate national sheep population (Statist ics Botswana, 2019) and this may be influenced by its hardiness and high tolerance to tick-borne infections (Nsoso *et al*., 2004). Another advantage is that the fat tail deposits of the sheep tend to provide a consistent energy supply, which in turn helps mitigate weight loss during dry seasons (Atti *et al*., 2004; Alves *et al*., 2013). This attribute tends to be highly associated with high fertility of fat tailed sheep (Dzama, 2016) like Tswana breed. Despite the good traits of this indigenous sheep, its productivity is largely affected by inadequate feed supply, poor husbandry practices, compromised health, high mortalities that characterized sheep production in economically disadvantaged regions of Botswana (Gaolebogwe, 1999; Segwagwe and Ramabu, 1999; Statistics Botswana, 2019; Bethelsson *et al*., 2020; Aganga *et al*., 2005). Inadequate nutrition in grazing ruminants often result in decreased feed intake, nutrients losses, poor body condition, weak immunity, reduced growth rates and ultimately low market prices (Ndlovu *et al*., 2007; Paul and Dey, 2015; Brown *et al*., 2015; Xu *et al*., 2017). Consequently, this has led to low rates of livestock sales in communal areas as evidenced by low offtake (3.9%) and selling price (P928.00) under traditional farming (Statistics Botswana, 2019).

Reduced feed abundance and poor quality forages in local rangelands is being exacerbated by the erratic rainfall and recurring droughts (Aganga *et al*., 2005). Consequently, this has significantly affected the nutrients supply to grazing animals resulting in poor performance in growing young ruminants (Kabir *et al*., 2002; Madibela *et al*., 2002; Momen *et al*., 2021). Inadequate feed supply in rangelands can be mitigated by use of crop residues in animal feeding systems (Madibela & Lekgari, 2004). However, crop residues (especially of cereal origin) contain high fibre and low CP contents, resulting in poor digestibility (Abera *et al*., 2018). To improve the utility of crop residues processing and supplementing crop residues with energy and protein concentrates before feeding, to improve their digestibility and efficiency has been recommended (Wanapat *et al*., 1996; Tafaj *et al*., 2001; Mthetho *et al*., 2015). While soya bean meal is regarded as the most preferred protein supplement, it is becoming expensive and unaffordable to the local communal farmers. The exploration of alternative economical protein sources has been an ongoing endeavour throughout the years (Khalid *et al*., 2011; Sekali *et al*., 2016; Obeidat *et al*., 2020).

Soya bean meal (SBM) is the most preferred protein source for ruminants as it contains the highest protein content and widely used in animal feeding (Yin *et al*., 2011; Zagorakis *et al*., 2018) as well as human nutrition (Sekali *et al*., 2016; Delele *et al*., 2021). Alternative protein sources to SBM such as canola meal (CM) and sunflower seed meal/cake on nutrient digestibility and sheep performances are being explored as potential replacement for the expensive soya bean meal. Previous studies have shown that both CM and sunflower seed meal/cake could either partially or fully replace SBM in fattening diets of small ruminants (Nkosi *et al*., 2011; Palmeiri *et al*., 2012; Sekali *et al*., 2016). Nevertheless, despite the substantial evidence of oilseed meals in influencing accelerated growth rates and weight gains in sheep and goats without compromising their health, limited information on the influence of sunflower seed cake (SSC) and Canola meal (CM) on the performance of indigenous Tswana sheep exists. Moreover, the influence of CM and SSC on blood metabolites of this sheep breed has not been evaluated. Therefore, this study investigated the effect of SSC and CM inclusion in lamb diets on nitrogen utilisation, growth performance and blood metabolites parameters of Tswana sheep weaners. It was hypothesised that partial substitution of SBM with CM and SSC as main protein sources in lamb diets has no significant effect on nutrient intake and digestibility, growth performance, nitrogen utilization and blood metabolites.

5.2 Materials and Methods

5.2.1 Site Description

This study was carried out at Botswana University of Agriculture and Natural Resources, Animal Experimental Unit, located in Sebele, Gaborone, over a period of ninety (90) days from December 2020 to February 2021. This site is situated at (25.94^0 S, 24.58 ^{0} E) at an altitude of 991m, with average annual rainfall of 500mm and hot summer (32 ^{0}C) and mild winter (21 ^{0}C) (World Weather Online, 2020).

5.2.2 Treatments and Experimental design

Thirty-six (36) castrated Tswana lambs with an average live weight (22.68 ± 2.57 kg) were randomly allotted to 36 individual cages. Subsequently (9) diets (total mixed rations) were also randomly allotted to the experimental cages. Each diet had 4 replicate cages and a lamb housed in an individual cage regarded as an experimental unit in a completely randomized design (CRD). The diets were formulated, according to NRC guidelines (1985) to meet nutritional requirements of sheep weaners in a feed lot system and contained 14% CP content. These d iets were formulated by substituting SBM component with CM or SSC at 0, 25, 50, 75 and 100 levels (DM basis). The dietary formulations are presented in Table 5.1.

5.2.3 Proximate composition of diets

Soybean meal and sunflower seed cake were purchased from local feed producer (Tholo Holdings Company, Gabane, Botswana) while CM (a produce of Southern Oil (PTY) LTD) was imported from South Africa. The gross composition of the diets is presented in Table 5.1. Dry Matter was determined by drying the samples (triplicates) at 65 ^{0}C in a forced-dry oven (Ecotherm - Labtec) for 48 hrs, according to (AOAC 2005, method no 934.01). The samples were then ground through 1-mm sieve by hammer mill (The FRITSCH Cross Beater Mill PULVERISETTE 16) for chemical analyses. Nitrogen (N) content and amount of OM were measured using the Kjeldhal method AOAC 1990; method no. 984.13 and 942.05 respectively. Crude protein (CP) was calculated as N × 6.25. Crude fat (Ether extract) was determined using AOCS Official method AM 5- 04 (X15 Extractor, Ankom Technology). The amounts of Neutral Detergent Fibre (after digestion with Sodium sulphite and Alpha-amylase), Acid Detergent Fibre and Acid Detergent lignin were determined using procedures of Van Soest *et al*. (1991) with ANKOM^{2000} Fiber Analyzer (Ankom Technology, 1998a). Evaluation of diets for gross energy was done using bomb calorimeter (CAL3k-AC NEXT GENERATION CALORIMETERS), while Ca and P were measured using Atomic Absorption Spectrometer (Agilent 200 series AA systems, Agilent Technologies, Inc 2014, USA) and GENESYS 10S UV- Vis Spectrophotometer (GEN10S UV-Vis-P, Thermo Fisher Scientific, Madison, WI 53711, USA) respectively.

Table 5.1 Gross composition of the experimental diets (% DM)

	[1]Experimental diets								
Components	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100
Maize stover	35	35	35	35	35	35	35	35	35
Canola meal	0	6.25	12.5	18.75	25.25	0	0	0	0
Sunflower cake	0	0	0	0	0	6.25	12.5	18.75	25.25
Soybean meal	25.25	18.75	12.5	6.25	0	18.75	12.5	6.25	0
Lucerne hay	10	10	10	10	10	10	10	10	10
Maize grain	23	23	23	23	23	23	23	23	23
Molasses meal	5	5	5	5	5	5	5	5	5
DCP	1	1	1	1	1	1	1	1	1
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Vit premix	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

CM = canola meal; SSC = sunflower seed cake; DCP = Dicalcium phosphate; Vit premix = vitamin and mineral premix; 1Experimental Diets: Control = with SBM as a major protein source, CM25 = with 25% of soybean meal replaced by CM, CM50 = with 50% of soybean meal replaced by CM, CM75 = with 75% of soybean meal replaced by CM, CM100 = with 100% of soybean meal replaced by CM, SSC25 = with 25% of soybean meal replaced by SSC, SSC50 = with 50% of soybean meal replaced by SSC, SSC75 = with 75% of soybean meal replaced by SSC, SSC100 = with 100% of soybean meal replaced by SSC

5.2.4 Animal Management

The lambs were purchased from Department of Agricultural Research, Ministry of Agriculture and Food Resources, at 6 months of age. They were ear-tagged and dipped using Flumethrin 1% m/v pour-on acaricide (Drastic Deadline™, Bayer® Animal Health, South Africa) on their first day of arrival. Then, on their second day, they were vaccinated against pulpy kidney and pasteurella diseases using Pulpy Kidney and Pasteurella Small stock vaccines from Onderstepoort Biological Products Company, South Africa. The animals were dewormed using a combination formula of Ivermectin 1% and vitamin A, D_3 and E (Ivermax + AD_3E, Ascendis, Animal Health, South Africa) and albendazole 1.9% (Valbezin, Prifer, South Africa) on the second and third week of arrival respectively. The lambs were then allocated to individual pens (1.5 m 1.0 m) with concrete floors, roofed with corrugated iron and naturally ventilated (1.2 m walls) (Figure 5.1). They were adapted to pens (Figure 5.1) and diets for fourteen (14) days before the start of experiment and on day-15 (commencement of the trial) animals were weighed (using a Mini Crane scale, Model: OCS-L) to determine their initial weights and then balance them. Diets were offered twice daily at 0800 and 1600hrs, at a rate of 3% of animal body weight and had *ad libitum* access to fresh water. Feed refusals were collected every morning before feeding and weighed, to estimate daily feed intake. Thereafter, weighing of animals was done every two (2) weeks to establish average daily gain and feed conversion rate (FCR) for ninety (90) days. Body condition scores (scale of 1 - 5) of all animals were taken during weighing time, as described by Kenyon *et al.* (2014) and Mvinjelwa *et al.* (2014). All procedures of experiment and animal management protocol were approved by the University Ethics Committee, North-West University, South Africa (ethical clearance: NWU 00359-19-A5).

Figure 5. 1 Lambs in their individual pens feeding in the morning

5.2.5 Growth Measurements

The following formulae were used to determine weight gain, average daily gain and feed conversion rate.

$$Feed\ Intake\ (kg) = Total\ feed\ offered\ (kg) - Total\ Feed\ refusal\ (kg)$$

$$ADG\ (t0,T) = \frac{W\ (T) - W\ (t0)}{T - t0}$$

where: ADG = average daily gain; t0 = initial time; T = final time (90^{th} day); W (T) = final weight and W (t0) = initial weight

The final body weight at day 90^{th} was taken and feed conversion ratio was calculated using the equation below

$$Feed\ conversion\ rate\ (FCR) = \frac{Feed\ Intake}{ADG}$$

Final BCS at day 90^{th} was also taken and change in BCS was calculated using following equation:

$$\Delta BCS\ (t0,T) = BCS(T) - BCS\ (t0)$$

Where ΔBCS = change in body condition score; t0 = initial time; T = final time (90^{th} day)

5.2.6 Digestibility trial

At the beginning of week ten, eighteen (18) animals (two per treatment) were randomly selected from the growth study and placed in individual metabolism crates to determine digestibility of diets. These animals were adapted for seven (7) days to the metabolic crates (Figure 5.2) and collection of samples (faeces and urine) were done on the following week (week 11) for a period of five (5) days. The collection of faeces and urine was conducted twice a day (0800 and 1600 hrs.) prior to feeding. After collection of samples as per treatments, faeces were weighed, thoroughly mixed in a clean bucket and took sub-samples (about 20% of the total weight) into plastic bags and stored in the fridge at temperature of -10 ^{0}C in labelled plastic bags until further analysis. Frozen faecal samples were thawed at the end of the digestibility trial and determination of DM, OM and N levels were done using similar procedures for diets evaluation). Urine was also collected every morning at 0800 hrs, weighed, subsampled (about 10%) and then stored frozen (-10 ^{0}C). A total of 100ml 10M H_2SO4 was added to the urine collection containers to prevent volatile N losses (Koralagama *et al.*, 2008). After collection, individual urine samples weighed, combined based on diets and then sub-sampled (collected 50 ml aliqoent) for later freezing and N analysis (Kanyinji *et al.*, 2017). Analysis for N in urine samples was also done at the end of digestibility study after firstly thawing the samples and digesting 5ml urine sample (Kjeldahl method; AOAC, 1990, I.D. No 954.01). The apparent digestibility of DM (DM), Organic Matter (OM) and crude protein (CP) was estimated using the following equation;

$$Apparent\ nutrient\ digestibility = \frac{Nutrient\ \ intake - faecal\ nutrient}{Nutrient\ intake} \times 100$$

	
Metabolic crate fitted with urine collecting	Animal resting on metabolic crate
	
Faecal collection and pooled as per diets	Sub-sampling of faecal material as per diets
	
Faecal sampling after sub-sampling every morning and stored frozen	Sub-sampling of urine every time before feeding and then freezing all samples collected

Figure 5. 2 Sample collection during in-vivo digestibility trial

5.2.7 Blood Metabolites

At the end of the ninety days feeding trial, blood samples were collected in the morning before being transported to abattoir for slaughtering and they were processed according to procedures described under Chapter 4 under section 4.3.4. However, determination of blood metabolites was done using Roche Cobas C111 Chemistry Analyser (Diamond Diagnostics, USA).

5.2.8 Statistical Analysis

The effects of diet on chemical composition of the diets (DM, OM, CP, NDF, ADF, ADL, Crude Fat, GE and Ash), nutrient intakes (DMI, OMI, CPI and GEI) and digestibility, growth parameters, nitrogen utilization and blood metabolites (creatinine, urea, total protein, albumin, globulin, total bilirubin, calcium, phosphorus, glucose, cholesterol, alkaline phosphatase, gamma glutamyltransferase) data were analysed using general linear model (GLM) of SAS (2012) and the following model was used;

$$Yij = \mu + Ti + Eij$$

Yij = response variables (chemical composition, nutrient intake and digestibility, growth parameters, nitrogen utilization and blood metabolites), μ = overall mean, Ti = effects of dietary treatment and Eij = random error. Means were separated using the Tukey's test and statistical difference was declared at $P \leq 0.05$.

5.3 Results

5.3.1 Chemical composition, nutrient intake and digestibility

The chemical composition of experimental diets is presented in Table 5.2 and it shows that the amount of DM, OM, ash and crude fat were significantly ($P<0.05$) influenced by dietary treatments. CM75 diet had the highest ($P<0.05$) content of DM while the lowest amount of DM was found in CM25 diet. In addition, SSC25 and control diets had the highest amount of OM while CM50 diet had the lowest contents of OM. Conversely, CM50 and SSC25 diets contained the highest and lowest amount of ash respectively. On the other hand, SSC100 and CM100 diets had statistically similar amount of crude fat and their fat contents were the highest when compared to other diets. The lowest fat content was found in the following control, CM25 and CM50 dietary treatments. Also, CM75 diet contained the highest ash content (7.91%) while SSC25 had the lowest (6.34%). In contrast, both diets had similar ($P>0.05$) levels of CP, NDF and ADF. Significant ($P<0.05$) variation was observed between the diets with regard to lignin content. The highest level of lignin was found in diets containing the high amounts of sunflower seed cake, SSC75 (20.80%) and SSC100 (20.94%) while lowest lignin content was observed in control. The results also indicated that the level of lignin increased with increase of inclusion levels of CM and sunflower seed cake in diets.

Table 5.2 Chemical composition of experimental diets (% of DM unless stated otherwise)

Item	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100	SEM
DM	90.68^{de}	89.10^{f}	89.64^{ef}	93.63^{a}	91.26^{cd}	91.28^{cd}	90.24^{def}	93.01^{ab}	92.16^{bc}	0.36
OM	93.52^{a}	92.79^{cd}	92.29^{ef}	92.09^{f}	93.29^{bc}	93.66^{a}	92.26^{ef}	92.59^{de}	93.08^{bc}	0.11
CP	14.88^{a}	14.96^{a}	14.69^{a}	14.64^{a}	14.19^{a}	14.86^{a}	14.09^{a}	14.64^{a}	14.33^{a}	0.34
NDF	35.11^{b}	35.04^{b}	35.78^{b}	37.03^{b}	38.06^{b}	36.35^{b}	35.5^{b}	36.47^{b}	42.35^{a}	1.30
ADF	21.46^{b}	22.31^{b}	22.92^{b}	25.75^{ab}	26.14^{ab}	23.01^{b}	23.74^{b}	24.20^{ab}	29.27^{a}	1.50
ADL	10.80^{d}	12.13^{cd}	14.26^{bcd}	16.96^{abcd}	17.30^{abc}	19.17^{ab}	19.33^{ab}	20.80^{a}	20.94^{a}	1.81
Crude Fat	3.00^{c}	3.13^{c}	3.30^{c}	4.37^{ab}	4.85^{a}	4.10^{b}	4.10^{b}	4.43^{ab}	4.86^{a}	0.16
GE (MJ/kg DM)	17.38^{a}	17.07^{abc}	16.69^{cd}	16.34^{d}	17.17^{abc}	17.15^{abc}	16.74^{bcd}	17.24^{abc}	17.32^{ab}	0.18
Ash	6.48^{ef}	7.21^{cd}	7.71^{ab}	7.91^{a}	6.72^{ef}	6.34^{f}	7.74^{ab}	7.41^{bc}	6.93^{cd}	0.11

^{a,b,c,d} Means in the same row with similar superscript are not different (*P*<0.05)

CM = canola meal; SSC = sunflower seed cake; DM = dry matter; OM = organic matter; CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin; GE = gross energy; Diets: Control = with SBM as a major protein source;, CM25 = with 25% of soybean meal replaced by CM, CM50 = with 50% of soybean meal replaced by CM, CM75 = with 75% of soybean meal replaced by CM, CM100 = with 100% of soybean meal replaced by CM, SSC25 = with 25% of soybean meal replaced by SSC, SSC50 = with 50% of soybean meal replaced by SSC, SSC75 = with 75% of soybean meal replaced by SSC, SSC100 = with 100% of soybean meal replaced by SSC

Table 5.3 shows the nutrient intakes and in-vivo digestibility levels of the investigated diets. It was observed that the dry matter, organic matter, gross energy and crude protein intakes were significantly ($P<0.05$) influenced by the dietary treatments. The highest ($P<0.05$) DM and OM intakes of were obtained in lambs consuming the SSC75 (1387.08g and 1287.52g) and CM75 (1365.86g and 1263.85g) diets when compared to the other diets. Similarly, the lambs fed the SSC75 diet also produced significantly higher intakes of gross energy and CP while those fed SSC25, SSC50 and CM50 diets had the lowest intakes. The lambs fed the SSC50 diet produced the lowest ($P<0.05$) value of CP intake. No difference ($P>0.05$) was observed with regard to CP digestibility. However, the control diet had higher ($P<0.05$) DM (78.98%) and OM (80.81%) digestibility compared to the canola and sunflower based diets.

Table 5.3 Nutrient intakes and digestibility in Tswana lambs fed diets containing different levels of canola meal and sunflower seed cake as substitution for soybean meal

[1]Parameters	[2]Experimental diets									
	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100	SEM
DMI (g/day)	1320.57^{abc}	1330.26^{abc}	1295.71^{abc}	1365.86^{a}	1306.38^{abc}	1234.35^{c}	1257.32^{bc}	1387.08^{a}	1335.24^{ab}	30.02
OMI (g/day)	1237.38^{abcd}	1235.36^{abcd}	1197.02^{bcd}	1263.85^{ab}	1226.08^{abcd}	1160.73^{d}	1168.53^{cd}	1287.52^{a}	1253.60^{abc}	28.04
GEI (MJ/day)	22.96^{ab}	22.70^{ab}	21.64^{b}	23.32^{ab}	22.32^{ab}	21.17^{b}	21.05^{b}	23.90^{a}	23.13^{ab}	0.61
CP-intake (g/day)	192.60^{abc}	193.28^{abc}	190.76^{abc}	197.50^{ab}	180.40^{bc}	181.15^{bc}	176.02^{c}	201.58^{a}	188.57^{abc}	5.32
Digestibility (%)										
DM	78.98^{a}	72.55^{abc}	68.18^{abc}	63.18^{c}	62.98^{c}	74.73^{ab}	69.59^{abc}	68.42^{abc}	64.83^{bc}	5.40
OM	80.81^{a}	75.47^{abc}	70.02^{bc}	65.52^{c}	66.82^{bc}	76.37^{ab}	72.12^{abc}	69.78^{bc}	67.79^{bc}	4.95
CP	75.68	69.89	70.36	63.03	61.45	74.69	69.20	69.56	61.06	5.79

^{a,b,c} Means in the same row with similar superscripts are not different (*P*<0.05)

[1]Parameters; DMI = dry matter intake; OMI = organic matter intake; GEI = gross energy intake; [2]Experimental diets[1]: Diets: Control = with SBM as a major protein source; CM25 = with 25% of soybean meal replaced by CM, CM50 = with 50% of soybean meal replaced by CM, CM75 = with 75% of soybean meal replaced by CM, CM100 = with 100% of soybean meal replaced by CM, SSC25 = with 25% of soybean meal replaced by SSC, SSC50 = with 50% of soybean meal replaced by SSC, SSC75 = with 75% of soybean meal replaced by SSC, SSC100 = with 100% of soybean meal replaced by SSC

5.3.2 Feed intake and growth performance

The results on body weight changes, feed intakes, daily gain, FCR and BCS are presented in Table 5.4. The results show that diet had a significant (P<0.05) effect on total and average daily gain, while no difference (P>0.05) was observed in final weight, feed intakes, FCR and BCS. Highest (P<0.05) daily and total gains were observed in lambs fed the CM100 (250g and 22.50kg) diet and lowest were observed in those fed the SSC25 (182.78g and 16.45kg) and SSC50 (212.50g and 19.13kg) diets respectively. Lambs that were fed the SSC25 diet had the lowest *(P*<0.05) final weight (38.90 kg) while those that were fed the control diet had the highest (44.88 kg). The present findings also demonstrate that all diets led to comparable improvements in fat and protein deposition in lambs, as indicated by the absence of any dietary impact on body condition scores.

Table 5.4 Feed intake and growth performance of Tswana lambs fed diets containing different levels of canola meal and sunflower seed cake as substitution for soybean meal

Parameters	[1]Experimental diets									
	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100	SEM
Total feed intake (kg)	122.34^{abc}	125.31^{ab}	121.42^{abc}	122.54^{abc}	120.24^{abc}	113.60^{c}	117.00^{bc}	127.14^{a}	122.66^{abc}	2.77
Final weight (kg)	44.88^{a}	44.33^{ab}	44.38^{ab}	42.78^{ab}	43.18^{ab}	38.90^{b}	41.50^{ab}	44.33^{ab}	43.08^{ab}	1.77
Total gain (kg)	21.35^{ab}	21.50^{ab}	20.53^{ab}	20.95^{ab}	22.50^{a}	16.45^{c}	19.13^{bc}	21.30^{ab}	19.93^{ab}	0.98
Average Daily Feed Intake (kg)	1.36^{abc}	1.39^{ab}	1.35^{abc}	1.36^{abc}	1.34^{abc}	1.26^{c}	1.30^{bc}	1.41^{a}	1.37^{abc}	0.03
Average Daily Gain (g)	237.22^{ab}	238.89^{ab}	228.06^{ab}	232.78^{ab}	250.00^{a}	182.78^{c}	212.50^{bc}	236.67^{ab}	221.39^{ab}	10.92
Feed conversion ratio	5.75^{ab}	5.86^{ab}	6.10^{ab}	5.89^{ab}	5.35^{b}	6.93^{a}	6.26^{ab}	5.89^{ab}	6.16^{ab}	0.38
Body condition score										
Initial	2.53	2.43	2.58	2.40	2.40	2.45	2.43	2.45	2.45	0.12
Final	4.80	4.85	4.88	4.75	4.80	4.68	4.73	4.82	4.80	0.12
Change	2.28	2.43	2.30	2.35	2.40	2.23	2.30	2.38	2.35	0.10

^{a,b,c} Means in the same row with similar superscripts are not different (P<0.05)

[1]Experimental Diets: Control = with SBM as a major protein source, CM25 = with 25% of soybean meal replaced by CM, CM50 = with 50% of soybean meal replaced by CM, CM75 = with 75% of soybean meal replaced by CM, CM100 = with 100% of soybean meal replaced by CM, SSC25 = with 25% of soybean meal replaced by SSC, SSC50 = with 50% of soybean meal replaced by SSC, SSC75 = with 75% of soybean meal replaced by SSC, SSC100 = with 100% of soybean meal replaced by SSC

The outcomes regarding the average daily feed intake and growth performance of lambs fed diets containing inclusion levels of CM and SSC are presented in Figure 5.3 and it was found that in most instances weekly feed intake (WFI) did not differ (*P*>0.05) across treatments during the feeding period. All diets resulted in rapid increases in average d aily feed intake (ADFI) of lambs on the week 2 (shown by high steep slope) except those fed diet SSC50. During that period (week 2), lambs fed diet SSC50 had lower intake (*P*<0.005) than those fed diets CM25 and SSC75. Figure 5.3 shows that lambs fed the SSC75 diet had the highest ADFI while those fed the SSC25 diet had the lowest. Reduced feed intakes were observed on the week 3, 4, 5 and 8 in all diets.

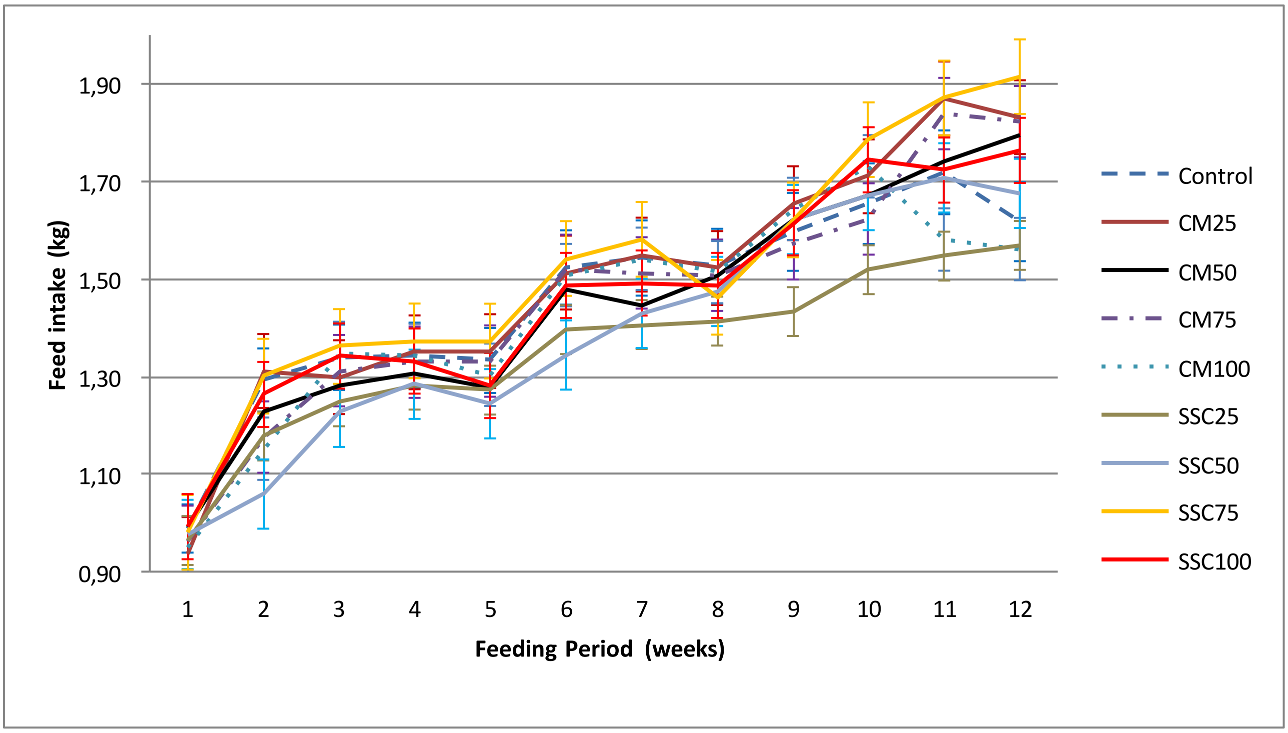

Figure 5. 3 Effects of replacing soybean meal in grower sheep diets with canola meal and sunflower seed meal on weekly feed intake of lambs

Body weight changes of the lambs over the experimental period are presented in Figure 5.4. There was an increase in the body weights of lambs in all treatments over the experimental period. In general, all lambs almost doubled their initial weights by the end of feeding period. Nevertheless, all the sheep had weight gains which were not statistically different although the lambs fed the SSC25 diet tended to have the lowest body weight during large part of the feeding period.

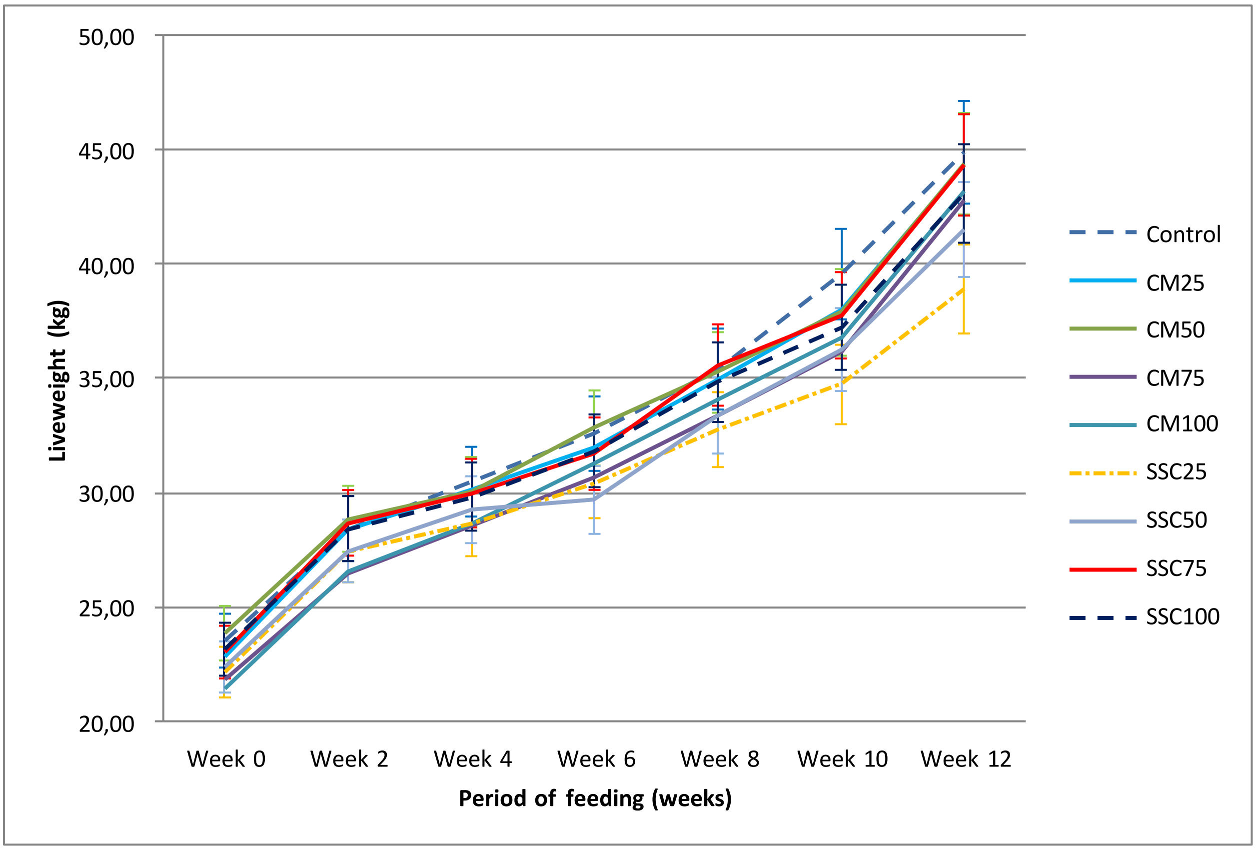

Figure 5. 4 Effects of diets containing canola meal and sunflower seed meal as substitution for soybean meal on live weight of Tswana lambs

5.3.3 Nitrogen utilization

Data on N intake, excretion in faeces and urine, nitrogen balance and retention are presented in Table 5.5. Generally, the results show that there were dietary effects on all investigated parameters, except urine nitrogen, nitrogen balance and retention. However, N intake followed the pattern for total feed intake, DMI and CPI where it was higher (P<0.05) in sheep weaners fed diet SSC75 when compared to those fed diets SSC25 and SCC50 (32.25 vs 28.99 and 28.14 g/ day). Also, faecal output was inversely related to ADF, DMD and OMD levels of the investigated diets and it was significantly higher for lambs fed diets with high inclusions of CM, CM75 (1.02 kg) and CM100 (0.98 kg), than those given control diet. Inversely, lambs fed control diet excreted higher (P<0.05) amount of urine than those fed diets SSC50 and SSC75. The findings of this study also show that the faecal material of lambs that consumed SSC75 and control diet contained higher (P<0.05) nitrogen amount (11.78 g and 11.74 g) than those fed SSC50 (7.12 g).

Table 5.5 Effect of feeding diets containing different levels of canola and sunflower seed meal as substitution for soybean meal on nitrogen utilisation by Tswana lambs

Parameters	[1]Diets									
	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100	SEM
Nitrogen Intake (g/day)	30.82^{abc}	30.93^{abc}	30.52^{abc}	31.60^{ab}	28.87^{cd}	28.99^{bcd}	28.17^{d}	32.25^{a}	30.17^{abcd}	0.75
Fecal (kg/day)	0.52^{b}	0.67^{ab}	0.82^{ab}	1.02^{a}	0.98^{a}	0.67^{ab}	0.75^{ab}	0.88^{ab}	0.95^{ab}	0.14
Urine (L/day)	0.92^{a}	0.71^{ab}	0.87^{ab}	0.72^{ab}	0.74^{ab}	0.83^{ab}	0.69^{b}	0.68^{b}	0.89^{ab}	0.07
N – in feces (g/day)	7.52^{ab}	9.45^{ab}	8.96^{ab}	11.78^{a}	11.21^{ab}	7.12^{b}	8.64^{ab}	9.76^{ab}	11.74^{a}	1.28
N – in urine (g/day)	6.42	5.52	5.37	6.64	6.03	5.44	5.68	5.72	6.89	1.40
N - balance (g/day)	16.89	15.96	16.19	13.21	11.63	16.44	13.86	16.76	11.55	1.95
N retained (as% of intake)	54.93	51.64	53.26	41.82^{a}	40.35	56.12	49.18	51.89	38.27	6.07

[a,b,c] Means in the same row with similar superscription are not signifivantly different (*P*<0.05)

[1]Diets: Control = with SBM as a major protein source, CM25 = with 25% of soybean meal replaced by CM, CM50 = with 50% of soybean meal replaced by CM, CM75 = with 75% of soybean meal replaced by CM, CM100 = with 100% of soybean meal replaced by CM, SSC25 = with 25% of soybean meal replaced by SSC, SSC50 = with 50% of soybean meal replaced by SSC, SSC75 = with 75% of soybean meal replaced by SSC, SSC100 = with 100% of soybean meal replaced by SSC

5.4.4 Serum biochemistry

The results on nutritional status of the lambs are presented in Table 5.6. From the table, it is clear that diet had no effect on any serum parameters apart from the urea. The highest urea levels were observed in lambs fed the CM50 diet whilst the lowest levels were obtained in the lambs fed the CM25 diet.

Table 5.6 Levels of blood metabolites related protein and minerals metabolism in lambs fed diets containing different levels of canola meal and sunflower seed meal

Parameters	[1]Diets									SEM	Range
	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100		
Creatinine (mmol/l)	59.95	65.65	61.88	60.96	56.46	67.30	68.70	56.03	67.30	3.52	53 – 133
Urea (mmol/l)	7.50^{ab}	5.90^{b}	12.05^{a}	9.10^{ab}	9.13^{ab}	9.10^{ab}	8.70^{ab}	8.15^{ab}	8.68^{ab}	1.25	1.8 - 7.1
Total Protein (g/l)	69.68	65.10	68.18	66.36	60.30	64.92	67.46	66.00	64.25	3.05	56 – 78
Albumin (g/l)	46.65	43.04	45.23	48.75	44.72	48.16	48.18	44.66	42.16	3.14	24 – 37
Globulin (g/l)	23.02	22.06	22.95	17.79	15.58	16.76	19.28	21.35	22.09	1.84	32 - 41
Total bilirubin (micrmol/l)	0.73	0.60	0.93	0.88	0.87	0.63	0.40	0.88	0.56	0.24	1.7 - 6.8
Calcium (mmol/l)	2.44	2.37	2.36	2.31	2.28	2.40	2.34	2.39	2.26	0.07	2.28 - 2.70
Phosphorus (mmol/l)	2.78	2.78	2.12	2.47	2.32	2.45	2.48	2.22	2.62	0.20	1.30 - 2.9

^{a,b,c} Means in the same row with similar superscript are not different (*P*<0.05)

CM = canola meal; SSC = sunflower seed cake; [1]Diets: Control = with SBM as a major protein source, CM25 = with 25% of soybean meal replaced by CM; CM50 = with 50% of soybean meal replaced by CM; CM75 = with 75% of soybean meal replaced by CM; CM100 = with 100% of soybean meal replaced by CM; SSC25 = with 25% of soybean meal replaced by SSC; SSC50 = with 50% of soybean meal replaced by SSC; SSC75 = with 75% of soybean meal replaced by SSC; SSC100 = with 100% of soybean meal replaced by SSC

Replacing soybean meal by CM and SSC did not affect (P >0.05) the levels of glucose, ALT and GGT in fattened lambs (Table 5.7). However, the concentration of serum glucose was below the recommended range for sheep, while the level for cholesterol was within the limits. On contrast, the serum activity of ALT amongst the animals fattened was above the normal range, while that of GGT were on the upper limits of recommended range.

Table 5.7 Energy profile and enzymatic activities of Tswana sheep lambs fed diets containing different levels of canola meal and sunflower seed cake

[1]Parameters	[2]Diets									SEM	Range
	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100		
Energetic Profile (mmol/L)											
Glucose	0.93	0.65	0.78	0.54	0.92	0.94	0.84	0.54	0.64	0.29	2.78 - 4.45
Cholesterol	1.82	1.17	1.14	1.41	1.38	1.42	1.02	1.38	1.46	0.16	1.14 - 2.12
Enzymatic Activities											
ALT (U/l)	367.60	419.18	273.15	294.13	295.53	301.80	288.25	254.55	246.05	40.18	50 - 228
GGT (U/l)	50.35	61.43	61.23	50.35	58.07	55.25	54.75	52.28	50.90	7.68	33 - 55

[1]Parameters: GGT = Gamma glutamyltransferase; ALT = Alanine aminotransferase; CM = canola meal; SSC = sunflower seed cake; [2]Diets: Control = with SBM only for reference purposes; CM25 = with 25% of soybean meal replaced by CM; CM50 = with 50% of soybean meal replaced by CM; CM75 = with 75% of soybean meal replaced by CM; CM100 = with 100% of soybean meal replaced by CM; SSC25 = with 25% of soybean meal replaced by SSC; SSC50 = with 50% of soybean meal replaced by SSC; SSC75 = with 75% of soybean meal replaced by SSC; SSC100 = with 100% of soybean meal replaced by SSC

5.4 Discussion

5.4.1 Nutrient Intake and Digestibility

All diets in this study produced daily DMI below the recommended amount (1.60 kg) for growing lambs (NRC, 1985) and this difference may be attributed to variations in genotypes and environment. The current study also indicates that all inclusion levels of CM produced similar daily intakes of DM, OM and CP to SBM. Despite no statistical difference in DMI between CM and SBM diets, inclusion of CM at 75% numerically increased DMI by 45.36g/d compared with inclusion of SBM at 100%. Paula *et al*. (2018) did not find differences in DMI in lactating dairy cows fed CM and SBM-based diets. On the contrary, a higher total DMI and dry matter digestibility was observed in growing lambs fed grass silage with canola meal replacing SBM (Petit *et al*., 1997). It was also observed the DMI (1285.86 g) of diets containing 25% of CM was higher than the highest value of DMI (1283g) observed by Khalid *et al*. (2011) in growing Kajli lambs fed diets containing CM at 28% inclusion rate. Furthermore, this study also found that all inclusion levels of CM resulted in similar daily GEI compared with Control diet except the CM50 diet, which produced comparatively the lowest GEI. This could be explained by the numerically lower DMI and OMI of diets CM50 than other canola based diets. In addition, the difference in DM and OM digestibility between control diet and that contained high levels of CM (CM75 and C100) in this work could be due to their difference in ADF contents. Increasing the level of CM in diets resulted in the increased fibre contents as observed in other studies (Sekali *et al*., 2016). The range of total DMI in this investigation (1234.35 kg) was higher than that (80.06 - 102.49 kg) of Tswana lambs fed cereal stover based diets supplemented with SSC in a study by Legodimo *et al*. (2016). Current results also show that the SSC can substitute SBM as the main protein source in the diets of growing Tswana lambs, as evidenced by similar intakes and digestibility of DM, OM and CP for diets containing different inclusion levels of SSC and those with SBM. Similar nutrient digestibility in this study could be explained by similar growth performance, a relationship observed by Zhang *et al*. (2021) and Wang *et al*. (2016) in fattening lambs and weaned pigs respectively. Additionally, similar findings were observed by Moura *et al*., (2015) and Irshaid *et al*. (2003) when growing sheep were fed on SSC as an alternative protein source to SBM. On the contrary, when they evaluated dietary inclusion rates (0, 7, 14 and 21%) of sunflower cake, Nkosi *et al*. (2011) reported lowest DMI, OMI and CPI in Mutton Merino lambs fed diets containing the highest level of sunflower cake. The authors associated this to high fibre content as a result of increasing levels of SSC. Lower digestibility of nutrients in growing lambs fed SSC than SBM was also observed by Alves *et al*. (2016). Besides, the findings of the present study showed that even though SSC diets produced similar nutrient intake and digestibility to SBM diets, comparatively higher nutrient intakes were observed in diets with high levels of SSC than that with low levels of SSC. This may be due to their differences in feed intake, amount of rumen degradable protein and supply of ammonia nitrogen for optimum microbial proliferation in the reticulorumen (Haddad *et al*., 2005; Javaid *et al*., 2008). Goes *et al*. (2019) and Oliviera *et al*. (2007) reported that SSC resulted in higher rumen degradable protein than SBM in growing ruminants and hence produced relatively higher concentration of rumen ammonia than SBM. An increase of available nitrogen supply in the rumen leads to improved feed intake and passage rate of nutrients (Obeidat *et al*., 2020) and reduced rumen filling effects (Plaisance *et al*., 1997). Inversely, diets that contained high amount of SSC had lower nutrients digestibility than those that had low amount of sunflower cake. This may be attributed to their high ADF contents and agrees with findings by Nkosi *et al*. (2011) on South Africa Mutton Merino lambs fed diets containing high levels of SSC. In conclusion, the present results on nutrient intakes and digestibility show that investigated protein supplements may influence feed intake and growth rate of Tswana lambs in a similar fashion. Similar digestibility of diets containing CM and SSC in lambs had been reported by Khalid *et al*. (2011). However, the studies by Sarwar *et al*. (2011) and Khalid *et al*. (2011) produced different nutrient intakes in growing lambs, with CM resulting in higher ($p<0.05$) DM and CP intakes than SSC. The tendency of CM to outperform other protein sources like lupin and urea in nutrients intake was also reported by Wiese *et al*. (2003) in lambs.

5.4.2 Feed Intake and growth performance

It was found that the ADG for all diets, except SSC25 diets, was above 275 g recommended for finishing lambs weighing above 40 kg (NRC, 1985). This study also observed that the results on final weight, total gain, ADG and FCR of growing lambs fed diets with increasing levels of CM in place of SBM were consistent with that by Sekali *et al*. (2016) and Sekali *et al*. (2020) on Mutton Merino and Meatmaster lambs respectively. However, the ADFI and ADG values obtained in the current study were higher than those obtained previously (Sekali *et al*., 2016; Sekali *et al*., 2020). Lack of differences in ADFI between the lambs fed diet containing CM and SBM may indicate that CM could replace SBM in lamb diets without affecting their palatability (Irshaid *et al*., 2003). This may also be associated with lack of significant differences in NDF levels in respective diets, a feed component that could limit feed intake in ruminants (Van Soest, 1994; Jurgens *et al*., 2002). Additionally, since Dabiri (2016) pointed that feed intake could be regulated by concentration of protein and energy in diets offered, lack of differences in ADFI in diets containing CM and SBM may also mean these rations had similar energy concentration. It had been noted by authors (Mahgoub *et al*., 2000; Wang *et al*., 2020) that feed intake tends to influence weight gain and FCR in different animals and hence lack of differences in weight gains and FCR in lambs fed canola based diets and SBMs in this study could be related to their similar feed intake.

The results of the present study also show that SSC included at all levels, except the lowest (25%), could substitute SBM in fattening diets for Tswana lambs, without affecting their feed intake and growth performance. Furthermore, lack of statistical differences on final weight, total feed intake, total gain, ADG and FCR between diets containing SSC and SBM in the present study is in agreement with findings by Irshaid *et al*. (2003) in Awassi lambs fed fattening rations with SBM being replaced by SSC (0, 50 and100%). Again, the current feed intake results were in agreement with that by Palmeiri *et al*. (2012) when they substituted SBM by SSC (0, 33, 66 and 100%) in growing kids. On the other hand, increasing levels of SSC in diets yielded contrasting results in work by Nkosi *et al*. (2011) in growing Merino lambs. It's noteworthy that the sunflower-based diets utilized in this study yielded increased feed intake, final weight, total gain, and average daily gain (ADG) in Tswana lambs when compared to the findings of Legodimo et al. (2016). In their study, which evaluated sorghum and millet stovers at various protein levels (13.50%, 15.50%, and 17.50% CP), they observed similar parameters in yearling Tswana castrates. This variation between the studies could be due to many factors including stage of animal growth and the level and quality of diets offered (Owens *et al*., 1993; Kenyon *et al*., 2014).

Although, canola and SSC influenced all tested parameters equally, numerically canola based diets produced higher weight gains and low FCR than sunflower based diets, except diet SSC75. Similarily, Khalid *et al*. (2011) reported significantly higher weight gains and better FCR in canola based diets than in sunflower based diets when fed growing lambs. The authors corroborated that this may indicate better nutrient utilization efficiency in canola based diets compared to sunflower based diets and other vegetable protein sources. The trend may be due to lower rumen degradable protein than SSC and higher by-pass protein in canola based diets than SSC ones (Canola Meal Feeding Guide, 2019; Oliviera *et al*., 2007). High by-pass protein tends to result in high dietary protein supply and absorption of amino acids post-ruminal digestion in small intestines, for utilization at tissue level. As a result, it was determined that this factor was linked to enhanced weight gains and improved feed efficiency in developing ruminants and high-yielding dairy animals (Garg, 1998). The final BCS of sheep shows that all investigated diets were of high quality and the sheep had adequate protein and excess energy intake and this resulted in comparably high deposition of fat and muscle in all lambs (Hersom & Thrift, 2018; Ghosh *et al*., 2019). Final BCS (4.68 - 4.85) in this study implies that all animals were well fed or becoming obese (Kenyon *et al*., 2014; Gnosh *et al*., 2019).

5.4.3 Nitrogen utilisation by lambs

Evaluating nitrogen balance in ruminants' diets is a very useful and accurate method of monitoring the value of protein to ruminant animals (Kanyinji *et al*., 2017). As expected, the current results showed that all animals were in a positive nitrogen balance. This also confirms that all lambs in this study gained weight and conserved nitrogen for their growing stage (Alves *et al*., 2014; Amuda *et al*., 2019). Furthermore, the current findings on CPI (28.87- 32.25 g/day) were relatively higher than 27.2 g/day in thin-tailed lambs supplemented with SBM and fish meals (Prima *et al*., 2019) and 15.65 g/day in West African Dwarf lambs fed diets (50% ensiled maize stove and 50% concentrate) in a work by Amuda *et al*. (2019), at protein level of 14% CP. Increasing the inclusion level of CM in lamb diets in this study did not affect its nitrogen utilization and this may be attributed to their similar feed intake, DMI and CPI. This direct relationship between nitrogen intake and DMI and CPI in lambs fed canola based diets is in agreement with findings by Sawar *et al*. (2011) and Khalid *et al*. (2012). In comparison to the control diet, the canola-based diets exhibited nitrogen intake that was consistent, as anticipated due to their higher crude protein intake. In this study increasing CM in lamb diets yielded numerically higher wet faecal output than that from lambs fed control diet and the opposite relationship was noted with urine output amongst these diets. Increased faecal weight in the present study was consistent with increased amounts of ADF and ADL and decreased digestibility of DM and OM for canola based diets. This inverse relationship between faecal water and urine outputs was also observed by Lascano and Heinrichs (2011) when evaluating high and low concentrate diets in dairy heifers. The authors associated this trend to water holding capacity of dietary fibre, such that higher levels of dietary fibre result in more water excreted in faeces than in urine. Furthermore, Lascano and Heinrichs (2011) also noted that increased urine output was associated with animals fed highly digestible diets which are in line with this current study. The level of faecal nitrogen for sheep fed canola based diets was similar to those fed control diet and this suggests that the quality of these diets did not differ (Monteith *et al*., 2014). The present findings also show that increasing canola inclusion level in the diets numerically increased their faecal nitrogen implying that increased amount of indigestible nitrogen and microbial protein production and reduced protein degradability and utilization of dietary nitrogen (due to high passage rate) (Wright *et al*., 2005; Monteith *et al*., 2014; Van Soest, 1994). Van Soest (1994) also reported that variation in quantity of faecal nitrogen in research animals could be influenced by the amount of microbial nitrogen originating from their large intestines. Hence, this might mean animals that consumed diets with high levels of CM (CM75 and CM100) had increased hindgut fermentation activity and microbial bodies. Furthermore, this low utilization of dietary nitrogen by lambs fed diets containing high inclusion levels of CM in the present study might be explained by their low nitrogen retention percentages (41.82 and 40.35%). The current investigation also show that Tswana lambs utilized nitrogen in diets containing SSC (except SSC50) and SBM in a similar fashion and this is in agreement with the findings by Moura *et al*. (2015) in growing lambs fed diets (12.7% CP) with similar inclusion levels of SSC. The present findings were also consistent with results found by Pereira *et al*. (2012) when they evaluated different inclusion levels (0, 7, 14 and 21) of SSC in the diets of lactating cows. It was also observed that, despite the insignificant difference in utilization of dietary nitrogen between control diets and SSC100 fed lambs, higher nitrogen retention was found in control diet than in SSC100 diets (54.93% vs 38.27%). Amongst the various sources for this variation, higher rumen undegradable protein (RUP) content in SBM than SSC (Walli *et al*., 1999) may have played a leading role. Higher RUP or bypass protein avails high amounts of essential amino acids for intestinal absorption and anabolic utilization by ruminants (Akhtar *et al*., 2016). The tendency of SSC to produce low nitrogen retention was also reported by Ahmed and Abdalla (2005) when compared with other oilseed cakes (cottonseed, sesame and groundnut) and attributed that to increased rumen pH and consequently increasing ammonia nitrogen instead of escape protein and microbial protein). It is understood that when animals undergo excessive absorption of ruminal ammonia into the bloodstream, they lose a substantial amount of energy due to the process of ureagenesis in the liver (Akhtar et al., 2016). This, in turn, negatively impacts gluconeogenesis (Noro & Wittwer, 2012) and leads to reduced weight gain.

The values for nitrogen utilization in the current study are higher than those observed by Ahmed and Abdalla (2005) in yearling desert lambs when fed sunflower diets with similar CP level (13.28% CP). Various factors may have led to this difference in nitrogen utilization like level of digestible nutrients, as expressed by percentage of OM, (92.26 - 93.66 vs 76.57%) and age of animals (weaners vs yearlings). According to their research, Alves *et al*. (2014), younger animals tend to utilize ingested nitrogen more effectively, resulting in higher retention percentages compared to adults. The difference in the findings on nitrogen intake between SSC50 and SSC75 diets might be due to their contrasting dry matter intake. Similar to the current findings of CM diets, increasing SSC amounts in lambs produced insignificant differences in wet faecal weight and faecal nitrogen though numerically it increased these parameters. This may also explain the numerically lower levels of nitrogen retention in animals feeding diet SSC100 than those fed SSC25 diet. Furthermore, it was observed that similar inclusion rates of SSC produced relatively higher range of nitrogen balance (11.55 - 16.76 g/day) in this study than the one (3.8 - 7.3 g/day) found by Moura *et al*. (2005) in lambs fed diets containing 12.7% CP. While the difference in nitrogen balance between the two studies might have been influenced by the difference in dietary protein levels (14.09 - 14.86 versus 12.7% CP), density of dietary energy and yield of rumen fermentation by-products (Meehan *et al*., 2021) and digestive capacity of sheep breed (Mwenya *et al*., 2003) might be responsible for this high difference in nitrogen balance. In addition, when evaluating the effect of breed on voluntary feed intake and total gain, Mann *et al*. (1986) reported higher nitrogen retention potential in tropical sheep breed than in temperate sheep breed when fed Bermuda grass pellets.

The results of this study also show that nitrogen utilization did not differ in lambs fed canola and sunflower based diets and this may be justified by insignificant difference in their urinary nitrogen, N-balance and nitrogen retention. This lack of difference in these parameters may indicate similar influence on rumen microbial growth, utilization of ammonia by rumen microbes and amount of absorbed excess nitrogen (Bonsi *et al*., 1995; Flachowsky & Lebzien, 2006; Meehan *et al*., 2021). In contrast, Sarwar *et al*. (2011) found higher nitrogen retention in lambs fed canola than those fed sunflower meal diets and associated that to better amino acids profile of CM and its higher influence for muscle building.

5.4.4 Blood metabolites

Serum biochemical parameters are normally used to indicate nutritional adequacy, physiological status, health and welfare of animals. The findings of this study showed similar amounts of serum metabolites among all treatments apart from the urea. This could be reflective of the fact that all animals were having the same nutritional status irrespective of the diet as observed in other studies (Caldeira *et al*., 2007). Similar trends on the serum levels of total protein, albumin and creatinine in lambs were also observed by Sekali *et al*. (2020) in Meatmaster lambs fed both untreated and heat-treated canola meals. The previous authors attributed this to the fact that all diets were sufficiently meeting the energy and protein requirements of the lambs despite the differences in protein sources.

However, the measured creatinine concentrations in this study were found to be below the normal levels, indicating effective dietary protein digestion and utilization by the lambs, a pattern that has been reported in other studies as well (Abdel-Ghani *et al*., 2011). The total protein, globulin and albumin concentration are also indicative of sufficiency of protein provision and digestion. All these parameters were above the normal range apart from the total globulin which appeared to be below the expected ranges for healthy animal. According to Yu *et al*. (2021), the main function of albumin is to transport nutrients and being the most abundant protein, high concentration in serum is largely associated with high intake of DM of protein by animals (Agenas *et al*., 2006; Paula *et al*., 2013). All other metabolites were within the expected ranges although there were no differences among the treatments confirming that the inclusion of CM and SSC did not negatively influence the nutritional status of the lambs.

5.4.5 Energy metabolites profiles and enzymatic activities.

The inclusion levels of CM and SSC at different levels did not affect the level of serum glucose in lambs in the current study as observed in other studies (Wijayanti *et al*., 2020). However, a contrasting trend was obtained by Omer *et al*., (2022) who observed that increasing inclusion levels of SSC increased blood glucose when compared to SBM. Nonetheless, the current results of serum glucose were below the normal range and also those obtained by Muruz *et al*. (2019) in lambs fed diets containing similar CP content to that in the current study. With regard to serum cholesterol, De Arujo *et al*. (2014) noted that assessment of cholesterol concentrations in animals is not only essential in measuring energy deficiencies, but also for detection of liver abnormalities that are often caused by excessive mobilization of body fat reserve. The present results showed that even though there were no differences among treatments the lambs fed the control diet had numerically higher amount of serum cholesterol. This confirms the superiority of SBM over CM and SCC as observed by Ghazalah *et al*. (2021) in broilers fed diets containing CM based diets. The obtained cholesterol levels in the current study are also lower than 4.62 - 5.23 mmol/l and 2.29 - 2.70 mmol/l obtained in Braki lambs (Omer *et al*., 2022) and crossbred (Dorper × Santa Inês) lambs (Araujo *et al*., 2014) respectively. The observed low cholesterol contents in the current study may suggest its potential for healthier and more acceptable meat quality (Mnisi & Mlambo, 2018; Ghazalah *et al*., 2021).

The available knowledge of liver activity shows that the concentrations of ALT and GGT are reflective of the liver or hepatic metabolism, with high level of these enzymes commonly regarded as biomarkers for liver damages induced by toxins in diet. In this study, no effect of diet on ALT and GGT were observed, suggesting similar health status of the lambs (Braun *et al*., 2010; Halakoo *et al*., 2020). While the levels of GGT were within the normal range, inferring no damage of cellular structure of hepatocytes (Cozma *et al*., 2015), the concentrations of ALT were above normal. According to Liao *et al*. (2016) and Oteng and Kersten (2020), increased amounts of serum ALT may be caused by increased hepatic metabolism.

5.5 Conclusion

The results of this study demonstrate that CM and SSC can be used to partially or completely replace SBM in the diets of growing Tswana sheep lambs without impacting their nutrient intake and digestibility, growth performance, nitrogen balance and most blood metabolites, except for urea. Since the investigated diets improved the growth performance of lambs without adverse effects on their health, further study is needed to determine the effects of the diets on the carcass yield and meat quality of lambs of this indigenous breed.

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CHAPTER 6.0 THE EFFECT OF CANOLA MEAL AND SUNFLOWER SEED MEAL INCLUSION IN LAMB DIETS ON CARCASS CHARACTERISTICS AND MEAT QUALITY

Abstract

This study evaluated the effects of replacement of soybean meal (SBM) with graded levels of canola meal (CM) or sunflower seed cake (SSC) at 0, 25, 50, 75 and 100% on carcass characteristics, meat quality attributes, proximate composition of meat and meat sensory evaluation of Tswana lambs. The lambs that were fed control diet yielded significantly higher percentage of hot carcass weight (HCW) and cold dressed mass (CDM) than those fed SSC25 and control diets. A higher ($P<0.05$) amount of subcutaneous fat was observed in lambs that were fed lowest level of CM than those fed the highest level of SSC. Furthermore, all diets, except SSC25, resulted in significantly similar weights of rib-chop, leg, chump, loin and rib-cuts in weaners. Meat from lambs fed the control diet and highest level canola meal had significantly higher drip loss percentage and tenderness (lowest firmness values). Compared to other diets, control diet resulted in lamb meat with the lowest ($P<0.05$) cooking loss percentage. Regarding meat chemical composition, lambs fed control and SSC75 diets produced meat with significantly lower moisture and higher fat contents than other diets. Although it ranked as the least effective in influencing the majority of assessed parameters, the SSC25 diet yielded significantly higher ($P<0.05$) scores for the appearance of cooked meat compared to the CM50 diet in sensory evaluations. Moreover, sensory scores on tenderness, juiciness and overall impression were significantly higher in meat of lambs fed diet SCC75 than that of lambs fed control diet. From the results, it can be concluded that CM or SSC as a replacement for SBM can be used as an alternative protein source up to 100% without negatively affecting dressing, lean muscle and fat percentages of fattened sheep weaners.

Again, all levels of CM and SCC except SSC25 produced weights of meat cuts that were similar to that of SBM. Sheep weaners fed SSC75 produced meat with the highest fat content and had the best tenderness, juiciness and overall score during sensory evaluation.

6.1 Introduction

Locally, mutton is largely produced from sheep raised on rangelands by communal farmers and its production and supply is largely affected by seasonal fluctuations in natural forage yield and quality, resulting in very low offtakes (Statistics Botswana, 2019). This has led to insufficient supply of mutton to meet national demand, consequently prompting imports of mutton and mutton products (Monkhei & Aganga, 2005). As with other developing countries, this is accentuating food insecurity resulting in reduced access and consumption of animal protein, subsequently increasing cases of maternal and children undernutrition amongst low-income and middle-income segment of the population (Black *et al*. 2008). Cabrera and Saadoun (2014) observed that mutton is good source of some essential amino acids and micro minerals like zinc, selenium, copper, iron and manganese that are critical for consumer health. In addition, the demand for dietary animal protein worldwide, especially in developing countries, is ever increasing due to increasing human population, income growth, urbanization and the changing consumption preference of meat products (Thornton, 2010; Wang *et al*., 2020). Therefore, this also calls for employment of management strategies by both producers and processors in the mutton industry locally to increase animal production, meat yield and quality as well as meat nutritional value and quality attributes.

In any animal production system, including sheep production, feed provision is of critical importance. Apart from enhancing growth and general animal performance, nutrition may also influence carcass yield, meat composition and quality. In many lamb feeding systems, soybean meal (SBM) is the most dominant protein source that is widely used (Nkosi *et al*., 2011; Zhang *et al*., 2021). Nevertheless, SBM based concentrates or supplements are expensive and unaffordable to the farmers. Soybean production in Botswana is generally low since much of the country has desert conditions that do not suit large scale production and poor rainfall. Therefore, soya bean imports are mainly done to meet the human nutritional needs. Alternative protein sources such as canola meal and sunflower seed cake are not consumed by humans and hence can be used as protein sources for sheep. In Chapter 5, these protein sources were evaluated and it was observed that they significantly improved growth performance, nutrient intake and protein utilization in lambs without causing any deleterious effects on their health. However, it is not known if the inclusion of these protein sources may have an effect on carcass and meat quality in indigenous Tswana lambs.

Meat quality assessment gives an indication of wholesomeness and healthiness of the meat which in turn affect consumer acceptability of the meat and hence their purchasing behviour (Hathwar *et al*., 2012; Xazela *et al*., 2017). A variety of factors, including nutritional changes have been observed to influence carcass composition and meat quality. Inclusion of canola meal and sunflower cake in lambs' diets was shown to improve carcass and meat quality traits (Sekali *et al*., 2016; Alves *et al*., 2016; Lima *et al*., 2018; Sekali *et al*., 2020) of meat type lambs raised in tropical climates. Nevertheless, there is general lack of information on the influence of Canola and SSC based diets on indigenous Tswana lambs. Therefore, the present study aimed to investigate the effects of feeding CM and SSC on carcass traits, meat quality attributes and sensory evaluation of Tswana sheep lambs. The study hypothesised that partial substitution of SBM with CM or SSC as main protein sources in lamb diets has no effects on carcass traits, meat quality attributes and sensory evaluation of Tswana sheep lambs.

6.2 Materials and methods

6.2.1 Study site, diet formulation and experimental design and management of animals

This study was carried out at Botswana University of Agriculture and Natural Resources, Animal Experimental Unit, located in Sebele, Gaborone whose location and climatic conditions are described in detail in Chapter 5, section 5.3.1. Experimental design and diets formulation, chemical composition of diets and animal management were also described in Chapter 5 under section 5.3.2, 5.4 and 5.3.3 respectively.

6.2.2 Slaughtering Protocol

At the end of the ninety-day feeding trial, the lambs were transported to the abattoir for slaughter. Before transportation, the lambs were fasted overnight with free access to water and pre-slaughter weights (PSW) were recorded in the morning. At the abattoir the lambs were stunned by captive bolt, bled, skinned and eviscerated, according to Livestock and Meat Industries Act 1 (2007). The carcasses were then weighed before being placed in the chiller.

6.2.3 Carcass traits

Immediately after slaughter, the carcasses were weighed to obtain the hot carcass weight (HCW) and the dressing percentage was determined by dividing HCW with PSW. After chilling for 24 hrs at 4°C (Figure 6.1), the carcasses were re-weighed to obtain the cold carcass weight (CCW). The following equations were used to determine hot carcass yield and cold dressing percentage:

$$Dressing\ (\%) = \frac{Hot\ Carcass\ Weight}{Pre\text{-}slaughter\ weight} \times 100$$

$$Carcass\ yield = \frac{Cold\ Carcass\ Weight}{Pre\text{-}slaughter\ weight} \times 100$$

After chilling for 24 hours, the carcass was dissected into two (2) equal halves according to dissection methods by Fisher and de Boer (1994), (Figure 6.1) then the left side was subsequently dissected into nine (9) wholesale cuts according to the Figure 6.2 (guide to lamb cuts by Freddy Hirsch, Cape Town, RSA) and all cuts were then weighed. The weight of wholesale cuts (neck, blade, shoulder, shank, rib chop, leg, chump, loin and rib-flank) were obtained and expressed as the percentages of the HCW. The area of rib-eye (*Musculus longissimus dorsi*), cut between the 12th and 13th ribs from the left half-carcass, was measured after tracing the area (of the caudal part) on to an acetate paper and measuring it using a digital planimeter (Koizumi Placom KP-90N planimeter, Japan).The leg and loin cuts from the right half-carcass of each animal were vacuum-packed separately in polyethylene bags and frozen at −18 °C pending the evaluation of proximate composition and meat quality traits (qualitative analysis) respectively.

Figure 6. 1 Frozen lamb carcasses inside the cold room

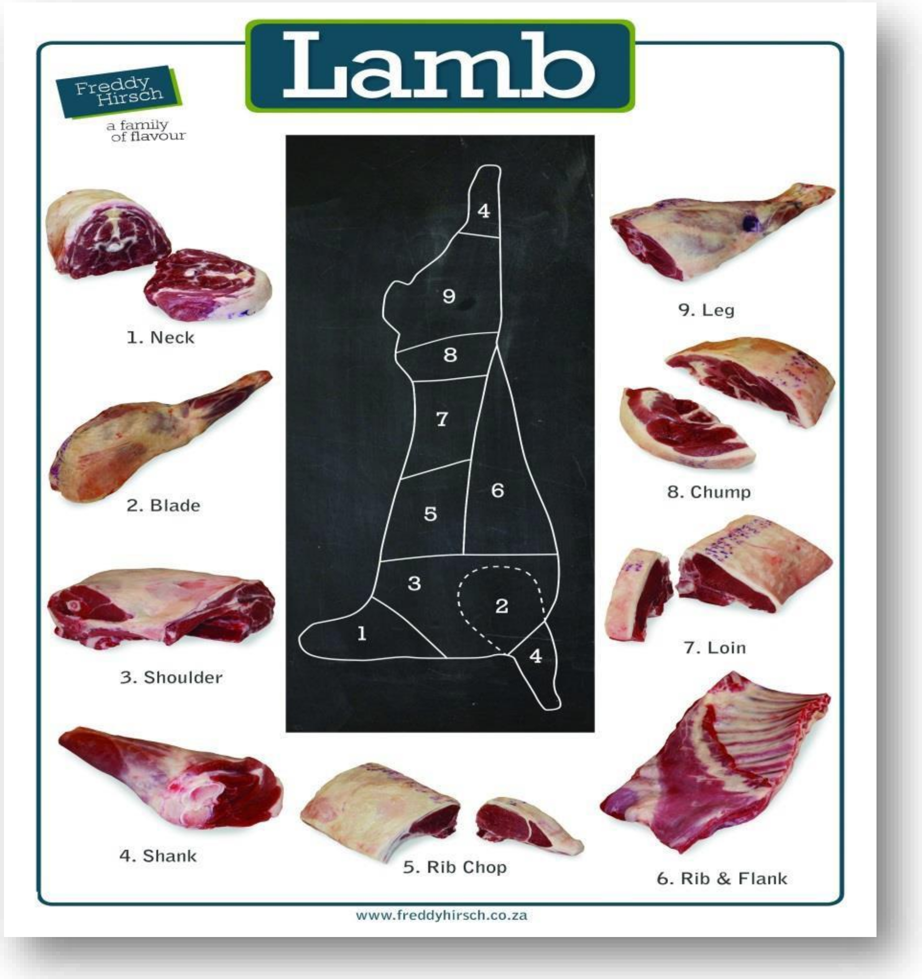

Figure 6. 2 Guide for lamb meat cuts (adopted from freddyhirsch.co.za)

6.2.4. Meat pH measurement

Meat pH and temperature were measured 24 hours after slaughter on the central area of loin (*longissimus dorsi* muscle) using a portable pH meter (H199163 Meat pH meter, Hanna Instruments, Rhode Island, USA) with a piercing electrode. After pH measurements, the *longissimus dorsi* was subsequently sampled for meat quality and sensory analysis.

6.2.5 Water Holding Capacity, Drip, Cooking loss and Tenderness measurements

The frozen loin cuts from the right half-carcass were thawed for thedetermination of water-holding capacity, drip loss, cooking loss and tenderness.

6.2.5.1. Water Holding Capacity (WHC)

Water holding capacity was determined following the pressure method (Warner, 2014) as the amount of water expressed from raw meat (30 g) held under 60 kg pressure between two (2) filter-paper (Grade 1 Qualitative Circles, 70mm circle, thickness 180 µm) on a flat surface for five (5) minutes. The weight of the meat samples before and after being pressured were measured using a digital scale sensitive up-to 0.001g (Sartorius TE313 S-DS, Sartorius AG, Gottingen, Germany) and the WHC was calculated as the percentage of the amount of water retained over the initial sample weight as follows.

$$WHC\ (\%) = \frac{Meat\ weight\ before\ pressure - Meat\ weight\ after\ pressure}{Meat\ weight\ before\ pressure} \times 100$$

6.2.5.2 Drip loss

About 2.5 cm thick meat strips (8 per treatment) weighing 60g were sampled from the loin eye muscle (*M. longissimus lumborum*), cut along the fibre direction and suspended vertically inside an airtight plastic container as shown in Fig 6.2. The containers we placed in the cold room for 72 hrs at 4^{o}C, according to procedures by Filho *et al*. (2017). After being removed from the containers, the samples were blotted dry with paper towels to remove surface water and then re-weighed.

Figure 6. 3 Gravimetric method for measuring drip loss by vertical suspension of meat strips

Then, the drip loss was calculated by subtracting the weight of blotted-dry meat strip from the initial sample weight and was expressed as a percentage relative to the initial sample weight (Honikel & Hamm, 1994; Wariss, 2000; Filho *et al*., 2017). The formula below was used to determine drip loss.

$$\%\ Drip\ loss = \frac{Initial\ weight\ of\ meat\ strip - Final\ weight\ of\ meat\ strip}{Initial\ weight\ of\ meat\ strip} \times 100$$

6.2.5.3 Cooking Loss

To determine cooking loss, the loin muscle (*M. longissimus lumborum*) was cut into 1.5 cm thick samples (8 per treatment) and weighed (W1) and placed in thin-walled plastic bags (as per their treatments), then cooked in water bath at 75 ^{o}C for 1hr as described by Hoofman *et al*. (2003). Thereafter, the cooked samples were removed from the water and cooled in cold water while still in their plastic bags, then removed from plastic bags, blotted dry with paper towels and weighed (W2). The cooking loss was calculated as percentage loss of weight during cooking relative to the weight of a raw meat sample, according to Wang *et al*. (2021), as follows:

$$Cooking\ loss\ (\%) = \frac{Raw\ meat\ weight\ (W1) - Cooked\ meat\ weight\ (W2)}{Raw\ meat\ weight\ (W1)} \times 100$$

6.2.5.4 Meat Tenderness

Meat tenderness was evaluated by a digital penetrometer (Digital Firmness Tester, Apollinaire Agro-technologies), commonly known as a food hardness tester -FHT, according to Baldassini *et al.* (2021) and Holman *et al*. (2015). The penetrometer was pressed against the cooked meat sample (processed according to procedures of cooking loss) and the resistance to penetration force was automatically measured (in kilograms) on its screen.

6.2.7 Chemical composition of lamb meat

To determine the moisture content of meat, the loin muscle (*M. longissimus lumborum*) samples (8 per treatment) were homogenously crushed in a blender, evenly spread in a crucible (≥ 50 mm diameter; ≤ 40 mm depth) and then dried in Force Air Oven (Ecotherm - Labtec) for 18 hrs at 100

^{o}C (AOAC, 2005; Method 950.46). Thereafter, the dried meat samples were ground using grinder (The FRITSCH Cross Beater Mill PULVERISETTE 16) and passed through a sieve size of 1 mm and nitrogen (N) content was determined according to Kjeldahl method (AOAC, 2005; method no. 928.08), with crude protein calculated as N x 6.25. On the other hand, fat (ether extract) was evaluated by procedures of AOCS Official method AM 5- 04 (X15 Extractor, Ankom Technology) with extraction time of 30 minutes and the percentage of fat were done as follows:

$$Fat\ (\%) = \frac{Pre-dried\ sample\ with\ bag\ (g) - Dried\ sample\ with\ bag\ (g)}{Original\ sample\ (g)} \times 100$$

The ash content of meat was determined following AOAC method 920.153 by weighing 2 g of dry meat samples into dry crucibles and combustion in a muffle furnace at 550^{o}C for 3 hours. Afterwards, the ashed samples were cooled in a desiccator and re-weighed to find out the ash percentage of meat, according to the following:

$$Ash\ (\%) = \frac{CSB\ (g) - CSA(g)}{CSB\ (g)} \times 100$$

Where CSB = weight (g) of crucible and sample before incineration

CSA = weight of crucible and sample after incineration

6.2.8 Sensory Analysis

Sensory analysis was performed according to procedures by Urbano *et al*. (2013), with meat samples taken from the loins (*longissimus lomborum*) of the right-half carcasses and cooked according to the methods used to determine cooking loss (Section 6.3.4.3). A total of seventy (70) untrained panellists were invited to assess coded meat samples using acceptance test with nine-point hedonic scale. This test considered the attributes of appearance, taste, flavour, tenderness and juiciness and nine points of the scale were as follows: 1 - dislike extremely, 2 - dislike very much, 3 - dislike moderately, 4 - dislike slightly, 5 - neither like nor dislike, 6 - like slightly, 7 - like moderately, 8 - like very much and 9 - like extremely. Each panellist was given a meat sample (about 12 g) from each treatment in a coded (three digits) disposable container (Figure 6.3) and still water at room temperature was also provided to remove any residual taste in between samples.

Figure 6. 4 Meat samples waiting to be served to testers

6.2.9 Statistical Analysis

Data on carcass traits, meat quality parameters, meat composition and sensory attributes were analysed using general linear model (GLM) of SAS (2012). The categorical data on sensory analysis was log transformed before analysis to achieve normality with results presented as back transformed means. The following statistical model was used:

$$Y_{ij} = \mu + T_i + E_{ij}$$

Yij = response variables (carcass traits, meat quality parameters, meat composition and sensory attributes), μ = overall mean, T_i = effects of dietary treatment and E_{ij} = random error. Means were separated using the Tukey's test and statistical difference was declared when $P \leq 0.05$.

6.3 Results

6.3.1 Carcass characteristics

The results on carcass characteristics of lambs are shown in Table 6.1. The results show that diet had a significant effect ($P < 0.05$) on all parameters apart from the dressing percentage, shoulder, shank, lean muscle and fat percentages of the lambs. The lambs theat were fed the control diet had the highest HCW followed by those fed the CM25 diet. The lambs that were fed the SSC25 diet had the lowest HCW. Similarly, the lambs fed the control diet had the highest CCW followed by those fed the CM25 diet. With regard to the ribeye area, a similar trend to the HCW was apparent with the lambs fed the control diet having the largest ribeye area followed by those fed the CM25 diet. Nevertheless, the lambs fed the CM25 diet has more fat compared to the other diets. With regard to yields of different carcass cuts, the lambs fed the control diet consistently had the highest values for all cuts apart from the shoulder cut which was higher in lambs fed the CM50 diet.

Table 6.1 Effects of substitution of soybean meal with different levels of canola meal and sunflower seed cake on carcass traits and composition of Tswana sheep lambs

Parameters	Dietary treatments								
	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100	SEM
Slaughter weight	44.88^{a}	44.33^{ab}	44.38^{ab}	42.78^{ab}	43.18^{ab}	38.90^{b}	41.50^{ab}	44.33^{ab}	43.08^{ab}	1.77
Hot carcass weight (kg)	21.10^{a}	19.85^{ab}	19.78^{ab}	18.80^{abc}	18.63^{abc}	16.83^{c}	18.50^{abc}	19.70^{ab}	18.38^{bc}	0.79
Cold carcass weight (kg)	20.23^{a}	19.03^{ab}	19.13^{ab}	18.05^{abc}	17.50^{bc}	16.13^{c}	17.75^{abc}	18.93^{ab}	17.50^{bc}	0.77
Shrinkage (%)	4.11^{ab}	4.13^{ab}	3.27^{b}	3.98^{ab}	5.50^{a}	4.33^{ab}	4.06^{ab}	3.91^{ab}	4.77^{ab}	0.61
Dressing percentage (%)	45.17	44.83	44.75	43.87	43.25	43.34	44.62	44.44	42.65	1.07
Ribeye										
Area (cm^{2})	14.68^{a}	14.28^{a}	11.67^{ab}	11.98^{ab}	10.46^{ab}	9.33^{b}	11.42^{ab}	11.92^{ab}	11.40^{ab}	2.03
Fat thickness (cm)	1.13^{ab}	1.25^{a}	1.08^{ab}	0.95^{ab}	1.03^{ab}	0.88^{ab}	1.00^{ab}	1.03^{ab}	0.78^{b}	0.13
Yield of Cuts (kg)										
Neck	0.52^{ab}	0.52^{ab}	0.59^{a}	0.35^{c}	0.53^{ab}	0.37^{bc}	0.42^{bc}	0.48^{abc}	0.44^{abc}	0.05
Shoulder	2.49	2.40	2.37	2.36	2.21	2.11	2.31	2.44	2.16	0.13
Rib-chop	1.02^{a}	0.87^{ab}	0.81^{abc}	0.89^{ab}	0.76^{bc}	0.61^{c}	0.87^{ab}	0.80^{abc}	0.88^{ab}	0.07
Leg	1.70^{a}	1.54^{abc}	1.49^{abc}	1.56^{ab}	1.38^{abc}	1.24^{c}	1.41^{abc}	1.64^{ab}	1.52^{abc}	0.09
Chump	1.69^{a}	1.52^{ab}	150^{ab}	1.52^{ab}	1.38^{ab}	1.30^{b}	1.37^{b}	1.61^{ab}	1.48^{ab}	0.09
Loin	1.56^{a}	1.54^{a}	1.32^{ab}	1.32^{ab}	1.47^{ab}	1.16^{b}	1.36^{ab}	1.47^{ab}	1.32^{ab}	0.10
Rib-flank	0.70^{a}	0.64^{ab}	0.60^{ab}	0.67^{a}	0.63^{ab}	0.49^{b}	0.59^{ab}	0.59^{ab}	0.69^{a}	0.05
Shank	0.35	0.35	0.33	0.32	0.32	0.23	0.32	0.32	0.30	0.02
Percentage of carcass weight										
Lean muscle (%)	70.49	69.57	68.99	69.17	69.47	69.28	67.74	71.82	70.21	1.28
Fat (%)	15.15	13.01	14.16	15.14	14.77	15.03	14.34	12.53	13.85	1.15
Bone (%)	14.36^{c}	17.42^{ab}	16.87^{ab}	15.69^{bc}	15.77^{bc}	15.70^{bc}	17.52^{a}	15.65^{bc}	15.94^{abc}	0.65

^{a,b,c} Means in the same row with similar superscript are not different (P<0.05); NS –not significant; *P<0.05

CM = canola meal; SSC = sunflower seed cake; [1]Experimental Diets: Control = with SBM as a major protein source; CM25 = with 25% of soybean meal replaced by CM; CM50 = with 50% of soybean meal replaced by CM; CM75 = with 75% of soybean meal replaced by CM; CM100 = with 100% of soybean meal replaced by CM; SSC25 = with 25% of soybean meal replaced by SSC; SSC50 = with 50% of soybean meal replaced by SSC; SSC75 = with 75% of soybean meal replaced by SSC; SSC100 = with 100% of soybean meal replaced by SSC

6.3.2 Meat quality parameters

The results on the effects of diet on meat quality parameters are shown in Table 6.2. From the results, it is evident that diet had no effect on meat pH and water holding capacity of lamb meat (Table 6.2). Nonetheless, diet significantly (P<0.05) affected the drip loss, cooking loss and tenderness of the meat. Lambs fed the control and CM100 diets had the highest drip loss percentages, while the lowest (P<0.05) drip loss percentages were obtained in lambs fed CM25 and SSC25 diets. Cooking loss was highest in lambs fed the CM50 diet while the lowest was obtained in lambs fed the SSC50 diet. With regard to tenderness, the lambs fed the control diet had the lowest value for firmness followed by those fed the CM100 diet. The lambs fed the SSC100 had the toughest meat compared to all other treatments.

Table 6.2 Loin meat quality data of growing Tswana sheep lambs fed different levels of canola meal and sunflower seed cake

Parameters	Levels of substitution by Canola meal and Sunflower seed cake (DM%)									SEM
	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100	
pH24	4.57	4.34	4.47	4.59	4.47	4.61	4.43	4.43	4.52	0.12
Water Holding Capacity (%)	13.57	13.96	11.95	12.11	17.79	13.21	12.76	12.21	13.95	2.86
Drip loss (%)	3.47^{a}	1.45^{b}	2.41^{ab}	3.54^{a}	3.92^{a}	0.68^{b}	2.12^{ab}	1.53^{ab}	1.78^{ab}	0.76
Cooking loss (%)	39.96^{ab}	39.94^{ab}	41.44^{a}	39.27^{ab}	40.73^{ab}	40.12^{ab}	38.55^{ab}	39.39^{ab}	38.02^{b}	0.85
Firmness (kg)	1.32^{b}	1.51^{ab}	1.64^{ab}	1.59^{ab}	1.42^{b}	1.60^{ab}	1.70^{ab}	1.86^{ab}	2.06^{a}	0.18

^{a,b,c} Means in the same row with similar superscript are not different (*P*<0.05); NS –not significant; **P*<0.05

CM = canola meal; SSC = sunflower seed cake; [1]Experimental Diets: Control = with SBM as a major protein source; CM25 = with 25% of soybean meal replaced by CM; CM50 = with 50% of soybean meal replaced by CM; CM75 = with 75% of soybean meal replaced by CM; CM100 = with 100% of soybean meal replaced by CM; SSC25 = with 25% of soybean meal replaced by SSC; SSC50 = with 50% of soybean meal replaced by SSC; SSC75 = with 75% of soybean meal replaced by SSC; SSC100 = with 100% of soybean meal replaced by SSC

6.3.3 Meat proximate composition

On evaluation of carcass composition, it was observed that the diets significantly (*P*<0.05) influenced all investigated parameters except the CP content (Table 6.3). The lowest moisture content was observed in carcasses from lambs fed the SSC75 and SSC100 diets. Nevertheless, the lambs fed the SSC75 and SSC100 obtained meat with the higher (*P*<0.05) fat content compared to the others. With regard to ash content, the highest value was obtained in meat from lambs fed the control diet. The inclusion of canola and sunflower cake appeared to lower the ash content of the meat particularly in lambs fed the canola-based diets.

Table 6.3 Proximate composition (%) of the loin carcass of sheep lambs fed different inclusion levels of soybean meal by canola meal and sunflower seed cake

Parameters	Dietary treatments									
	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100	SEM
Moisture	66.71^{a}	68.75^{a}	66.38^{a}	68.60^{a}	68.91^{a}	68.11^{a}	68.36^{a}	62.34^{b}	62.37^{b}	1.43
Fat	10.76^{bc}	10.70^{bc}	11.78^{b}	10.22^{c}	10.51^{bc}	11.02^{bc}	10.47^{bc}	16.20^{a}	15.44^{a}	0.42
Crude Protein	21.17	21.29	20.17	19.72	19.90	19.75	19.60	19.74	20.27	0.59
Ash	1.42^{a}	0.95^{ab}	1.22^{ab}	1.04^{ab}	0.80^{b}	1.17^{ab}	1.18^{ab}	1.04^{ab}	1.22^{ab}	0.14

^{a,b,c} Means in the same row with similar superscript are not different (*P*<0.05); NS –not significant; **P*<0.05

CM = canola meal; SSC = sunflower seed cake; [1]Experimental Diets: Control = with SBM as a major protein source; CM25 = with 25% of soybean meal replaced by CM; CM50 = with 50% of soybean meal replaced by CM; CM75 = with 75% of soybean meal replaced by CM; CM100 = with 100% of soybean meal replaced by CM; SSC25 = with 25% of soybean meal replaced by SSC; SSC50 = with 50% of soybean meal replaced by SSC; SSC75 = with 75% of soybean meal replaced by SSC; SSC100 = with 100% of soybean meal replaced by SSC

6.3.4 Sensory analysis

This study revealed that, generally, substituting soybean meal with CM and SSC significantly affected all the sensory attributes apart from the taste and flavour (Table 6.4). The meat from the lambs fed the SSC25 had the most desirable appearance as shown by the highest score it was given. Meat from lambs fed the CM50 diet with the lowest score appeared to be most disliked. In term of tenderness, the meat from lambs fed the CM50 and SSC25 diets were ranked as the tenderest compared to the other treatments. The meat from lambs that were fed the SSC75 had the highest scores for juiciness followed by those fed SSC25 diet. The meat from lambs that were fed the control diet received the lowest score for juiciness. Generally, the meat from lambs fed the SSC diet received favourable scores in all sensory parameters when compared to those fed the control and the CM based diets.

Table 6. 4 Sensory attributes of the meat of lambs fed different levels of canola meal and sunflower seed cake

Parameters	Dietary treatments									SEM
	Control	CM25	CM50	CM75	CM100	SSC25	SSC50	SSC75	SSC100	
Appearance	6.31^{ab}	6.10^{ab}	5.79^{b}	6.15^{ab}	6.40^{ab}	6.57^{a}	6.24^{ab}	6.40^{ab}	6.32^{ab}	0.22
Taste	6.10	6.33	5.96	6.10	6.10	6.36	5.61	6.31	6.07	0.23
Flavour	5.80	6.09	6.08	6.18	6.32	6.39	5.71	6.41	6.14	0.22
Tenderness	6.09^{c}	6.52^{abc}	6.68^{abc}	6.35^{bc}	6.67^{abc}	6.87^{ab}	6.20^{bc}	7.23^{a}	6.53^{abc}	0.23
Juiciness	5.10^{d}	5.71^{abcd}	5.59^{abcd}	5.35^{bcd}	5.93^{abc}	6.04^{ab}	5.54^{abcd}	6.31^{a}	5.19^{cd}	0.26
Overall	5.84^{b}	6.41^{ab}	6.32^{ab}	6.16^{ab}	6.46^{ab}	6.51^{ab}	6.04^{ab}	6.60^{a}	6.29^{ab}	0.22

^{a,b,c} Means in the same row with similar superscript are not different (*P*<0.05); NS –not significant; **P*<0.05

CM = canola meal; SSC = sunflower seed cake; [1]Experimental Diets: Control = with SBM as a major protein source; CM25 = with 25% of soybean meal replaced by CM; CM50 = with 50% of soybean meal replaced by CM; CM75 = with 75% of soybean meal replaced by CM; CM100 = with 100% of soybean meal replaced by CM; SSC25 = with 25% of soybean meal replaced by SSC; SSC50 = with 50% of soybean meal replaced by SSC; SSC75 = with 75% of soybean meal replaced by SSC; SSC100 = with 100% of soybean meal replaced by SSC

6.4 Discussion

6.4.1 Carcass traits and proximate composition

The findings that the lambs that were fed the control diet had the highest slaughter weight, HCW and CCW were expected. This could be due to the fact that the control diet containing the SBM provides the ideal diet for feedlot lambs ensuring highly digestible and accessible protein compared to the other diets. Similar findings were observed in lambs fed diets containing canola meal (Sekali *et al*., 2016; Alves *et al*., 2016). Although the lambs fed the control diet had higher values for the carcass traits, the differences with the lambs fed diets containing CM and SCC was marginal. The inclusion of CM and SCC in the diets did not dramatically reduce the carcass traits measurements as observed in other studies (Sekali *et al*., 2020). Although there was no effect of diet on dressing percentage, the lambs from this study produced numerically higher carcass weight and cold dressing percentage compared to those obtained by Legodimo (2013) on yearling Tswana sheep fed on sunflower based diets. Nevertheless, the current study yielded lower values for dressing percentage than 46.45% observed by Ruzic-Muslic *et al*. (2011) in weaned lambs fed diets containing SSC as the main protein source. Even though the chilling loss/shrinkage percentage has been reported to be influenced by the amount of fat cover (Carneiro *et al*., 2020), the present values of shrinkage and ribeye fat thickness do not reflect such relationship.

According to Carneiro *et al*. (2020), the determination of weights of meat cuts is a crucial practice in the assessment of commercial quality of the carcasses. Different meat cuts often have economic values that differ. Generally, the weights of ham and loin are the best indicators of maximum meat yield on a carcass (Piola Junior *et al*., 2020). Considering this the average weights of ham (leg and chump) and loin in this study ranged from 45.06 to 49.87% of the carcass weights, indicating a good meat yield, according to the previous literature. The observed high weights for meat cuts in lambs fed the control diet is consistent with the obtained high slaughter and carcass weights in the same group. In terms of carcass composition, the obtained lean muscle and fat contents in this study are consistent with the findings by Palmeiri *et al*. (2021) in small ruminant offered different levels of sunflower meal. Nevertheless, the current results on bone proportion are contrary to the findings from previous studies (Piola Junior *et al*., 2020).

6.4.2 Meat quality

According to Santos *et al*. (2013), meat colour, texture and marbling are the important factors influencing meat quality perceptions and purchasing decision by consumers. Meat colour and texture may be influenced by meat pH which is also influenced by post-mortem biochemical activity. The observed lack of effect of diet on meat pH and WHC is consistent with the results from other studies (Sekali *et al*., 2016; Sekali *et al*., 2020; Oliviera *et al*., 2015). Similar results were also reported by Rizzi *et al*. (2002) in Sarda lambs fed complete pelleted diets containing SBM, extruded soybean and crushed sunflower seeds. According to Sekali *et al*. (2016), similar meat pH may be due to the similar management of animals during the growth study. Nevertheless, the meat ultimate pH values obtained in the current study were very much lower than the recommended range of 5.2 to 5.8 (Suliman *et al*., 2021). According to Wariss (2000), lower meat pH falls is undesirable as it may induce denaturation of muscle proteins, resulting in reduced capability to bind water and increased drip loss. Significant differences in drip loss, cooking loss and tenderness in the current work may be attributed to difference in fat cover (ribeye) and fat composition. In their work, de Lima Junioe *et al*. (2016) reported a negative correlation between fat content and cooking loss and shear force/tenderness and pointed that since fat has lower water content, meat muscles that are richer in intramuscular fat have lower drip loss. In the current study the inclusion of SSC in diets appeared to reduce the drip loss. However, no effect of diet on cooking loss and drip loss was reported in some studies (Sekali *et al*., 2020; Ruzic-Muslic *et al*., 2011).

6.4.3 Proximate composition of the loin carcass

The proximate composition of meat has been reported to be influenced by various factors like diet, sex and animal breed (Suliman *et al*., 2021). The present average value for moisture content of loin muscle of Tswana lambs (66.73%) was lower than the 73.34 to 74.40% reported for different fat-tailed breeds (Awassi, Harri and Najdi). Nevertheless, the moisture content (68.60%) of loin meat from lambs fed CM75 diet compares well with the 69.46% of finishing sheep fed canola grains at 20% of the total ration (Picanto *et al*., 2020). While the mean fat content in the current study was higher than that reported by Yousefi *et al*. (2012) in another fat-tailed breed (Chall) raised under semi-intensive system the values were lower than the 20.37% reported by Tshabalala *et al*. (2003) in Damara sheep. The lack of significant impact from increasing levels of canola meal on the protein content of meat in this study is in line with the findings reported by Gopinger *et al*. (2014). Nevertheless, the inclusion of canola meal was observed to alter protein content of meat (Moraes *et al*., 2016). Differences in current values of meat fat may be due to various factors like net energy intake (above maintenance) (Schumacher *et al*., 2022), amount and relative percentage of acetate and propionate fatty acids produced in the rumen (Kotupan & Sommart, 2021). These fatty acids had been identified as the main precursors for fatty acids and biosynthesis in ruminants. In addition, Ladeira *et al*. (2016) highly associated high concentration of rumen propionate and lactate with intramuscular fat in ruminants. Hence, significantly higher amount of fat in Tswana sheep weaners fed diets SSC75 and SSC100 than those fed other diets might be due to high production level of fat precursors.

6.4.4 Sensory attributes

The overall means of all investigated sensory attributes of lamb meat were greater than 5.0, showing that all the diets produced meat that was acceptable (Sekali *et al*., 2016). In terms of appearance, all diet containing SSC produced lamb meat with desirable appearance as reflected by the high scores given to the SSC diets. However, the lack of differences in terms of taste and flavour among the diets confirms the fact that the inclusion of CM and SSC in diets has no negative effect of the two sensory parameters. Tenderness and juiciness are positively correlated parameters (Sekali *et al*., 2016) and the results of the current study appeared to show that the inclusion of CM and SSC in diets improved the tenderness and juiciness of the meat when compared to the control diet. This is consistent with results from other studies (Sekali *et al*., 2016). The observed high overall sensory scores in CM and SSC fed lambs are consistent with finding from other studies (Sekali *et al*., 2016; Gopinger *et al*., 2014). These high overall acceptability scores in lambs fed canola meal and SSC based diets shows that these protein sources could replace SBM in lambs' diets without affecting the overall acceptability of the meat.

6.5 Conclusion

Based on the outcomes, the incorporation of CM and SSC into the diets led to reduced slaughter weights and carcass characteristics in comparison to the control group. Nevertheless, the differences were not too wide. With regard to meat quality parameters, diet had no effect on meat pH. However, cooking loss was highest in lambs fed the CM50 diet while the lowest was obtained in lambs fed the SSC50 diet. The lambs fed the control diet had the lowest value for firmness followed by those fed the CM100 diet. The lambs that were fed the SSC100 had the toughest meat compared to all other treatments. Diet had no effect on the CP content of meat from all treatments. Based on meat evaluation by meat consumers, sensory scores of tenderness, juiciness and overall analysis were significantly higher in animals supplemented with SSC75 that fed on SSC75 than those that were fed control diet. Overall, CM and SSC inclusion in diet appeared not to negatively affect carcass characteristics and meat quality. In fact, the inclusion of CM and SSC in diets improved the general acceptability of meat.

6.6 References

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CHAPTER 7.0 GENERAL DISCUSSION, IMPLICATIONS AND RECOMMENDATIONS

7.1 General discussion and implications

The study was carried out to assess the quantities and quality of the available feed resources for sheep, to determine feeding strategies amongst communal sheep farmers and to assess nutritional and health status of communal sheep during the dry season. The study also determined the nutrient intake and digestibility, growth performance, nitrogen utilization, blood metabolites profiles, weights of offals, carcass traits and composition, meat quality characteristics and meat sensory evaluation of lambs fed canola meal and sunflower cake as an alternative to soybean meal. This chapter summarises the findings from the four studies and give recommendations on how the findings may be applied to improve sheep farming amongst small holder farmers. Furthermore, this chapter suggests future research works in relation to improving feed supply and quality, optimum nutrients utilization and solving problems in ruminant nutrition and feeding faced by small holder farmers.

Within the local context, sheep production faces a range of challenges, including the significant occurrence of animal diseases and parasites, as well as insufficient feed supply and low quality of forage in the rangelands. These factors collectively contribute to suboptimal performance in sheep. The poor performances of the animals as a result of high nutritional stress amongst grazing animals are further exacerbated by high stocking rates, low feed supplementation rates and poor feeding practices. To appropriately advise local sheep farmers on suitable feeding strategies, it was crucial to identify what and how they are currently feeding their animals and how. In Chapter 3, it was hypothesised that there no inventory of feed resources and feeding practices for the dominant sheep breed kept by smallholder farmers. The findings indicated that the rangelands were the major source of feed to communal sheep, followed by crop residues (maize, sorghum and cowpeas), proteinaceous forages (lucerne and lablab hays), brans/molasses and protein/mineral blocks. The results also showed that majority of communal sheep farmers practise blanket supplementary feeding daily and fed mixture of milled crop residues, bran/molasses and salt during dry seasons. Unfortunately, very few communal sheep farmers (< 4%) in this study area supplemented their animals with oilseed meals, despite their high potential to improve feed intake, digestibility and utilization. This is probably due to the unavailability of information on the incorporation of such feed resources in their animal feeding strategies. However, there is need to promote efficient utilization of cereal crop residues and use of oilseed meals in sheep feeding. This has high potential to increase animal productivity rates, reduce farming losses and increase returns amongst smallholder sheep farming.

In Chapter 4, the nutritional profiles of natural pastures and sheep kept by smallholder farmers were evaluated. The results of this chapter show that the investigated districts (Kgatleng, South East, Southern and Kweneng) had similar plant densities, but different herbaceous biomass yields and cover percentages of woody plants. The results on cover percentage of woody plants further indicated that all districts except the Southern district are bush encroached, predominantly thorny and less browsed plants. The current findings also reveal that the nutritional content of herbaceous forage in the investigated communal rangelands during dry seasons is inadequate for a mature sheep. This chapter hypothesized that the quality of rangeland forages has no significant effect on body weights, body condition scores and blood metabolites profiles of different classes of sheep raised on communal rangelands during hot dry seasons. The findings of this study show that the live body weights and BCS were affected by feed supply on the rangeland (district) and physiological status of sheep respectively. Also, the BCS of suckling ewes (lower than 3) showed that they were the only ones in poor body condition. However, the findings on blood metabolites profile show that all ages of sheep in the study area had hypoglycaemia, while those in the South East district had severe hypoproteinemia and hypocalcemia during dry seasons. The present results agree with proposed alternative hypothesis that the quality of rangeland forages significantly affected the nutritional status of communal sheep during dry seasons locally. Below normal concentration of blood metabolites illustrates insufficient intakes of energy, protein and mineral amongst communal sheep, a scenario that may subsequently result in low productivity rates in animals. Hence, there is a need to produce cheap and high quality diets for communal sheep during hot and dry seasons to improve their growth and off-take rates.

Lambs fed with cereal stover diets supplemented with oilseed meals are reported to have improved production, reproduction and health performances. In Chapter 5 diets were formulated for lambs to assess with the effects of inclusion of canola meal and sunflower cake in diets on nutrients utilization and growth performance in Tswana lambs. This chapter hypothesised that there was no significant difference in nutrient intake and digestibility, growth performance, nitrogen utilisation and serum biochemistry parameters of Tswana lambs fed canola meal or sunflower cake as partial or total substitutes for soybean meal. The results of this study showed that lambs fed diets containing only soybean meal, canola meal or sunflower seed cake as main protein source had similar nutrient intakes, feed intake, weights gain and FCR. The findings also show that CP-digestibility, feed intakes, final weights, FCR, BCS, nitrogen utilization and blood metabolites (except urea) did not differ when soybean meal is partially substituted with canola meal or sunflower. These results imply that CM and SSC can partially or totally replace SBM as the main protein supplement in diets for growing Tswana lambs without adverse effects on liver functions. Furthermore, since the inclusion of CM or SSC in diets improved growth performance of lambs and did not negatively affect their nutritional and health status; it may be suggested that carcass traits, meat quality and meat sensory attributes would also be improved. Therefore, it was necessary to assess the effect of CM or SSC inclusion in diets on carcass characteristics and meat quality of Tswana lambs.

In Chapter 6, the effects of canola and sunflower cakes inclusion in diets on carcass characteristics and meat quality in lambs was determined. Findings from the study showed that inclusion of CM or SSC in lambs' diets positively influenced all their carcass characteristics, meat proximate composition, meat quality and sensory attributes of meat. Therefore, whilst SBM is the most preferred protein source, in resource deprived areas such as the communal regions of Botswana, alternatives such as the Canola and sunflower cakes can be prudent sources of protein to improve performance of sheep in the communal areas.

7.2 Recommendations

To promote the meat and other by-products of indigenous sheep there is a need to assist small holder farmers in Southern Africa to develop feeding strategies and embracing precision animal feeding practices, which can subsequently lead to reduced production costs. To successfully achieve this, it is essential to conduct seasonal monitoring of animal body weights, body condition scores and concentration of blood metabolites of indigenous sheep breeds in the region and identify their main nutritional and health problems.

Again, since communal rangelands have poor feed supply and quality during dry seasons and consequently poor nutritional and health status of grazing sheep, it is recommended that smallholder sheep farmers utilize either canola meal or sunflower seed cake to improve the quality of cereal crop residues based diets and growth rate, health, carcass yield and quality of indigenous sheep breeds. Encouraging the use of affordable and high-quality oilseed meals in fattening indigenous livestock can be achieved by providing training to extension workers in livestock agriculture. This approach holds merit as it would improve the availability of meat, make it more affordable and contribute to reducing regional undernourishment rates. It is also recommended that extensive education be offered to livestock farmers and extension workers on the importance of determining nutritional status of grazing animals on seasonal basis and using such information to influence decisions on production, reproduction, feeding and marketing of livestock.

7.3 Further research recommendations

1. It is essential to study the effect of cereal crop residues-based diets containing CM and SSC on the rumen fermentation dynamics and protozoa population in Tswana sheep lambs.
2. In order to escalate consumption of meat from Tswana sheep there is a need to generate more information on its health benefits and hence the effect of CM and SSC on fatty acid profile and cholesterol levels of meat from Tswana sheep lambs need to be studied.
3. Research on the effect of CM or SCC on the reproduction performance of Tswana sheep is highly needed to improve fertility, births and weaning rates in sheep.
4. Studying the influence of CM and SCC on the milk production in lactating indigenous ewes and rumen development of their suckling lambs

5. Evaluation of the growth performance, carcass characteristics and percentage of tissues of Tswana sheep lambs subjected to different levels of energy in the cereal crop residues-based diets containing CM or SSC.