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The use of *Moringa oleifera* and *Leucaena leucocephala* tree leaves to improve smallholder goat production in Mozambique

By

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Animal Science in the Department Animal and Wildlife Sciences, Faculty of Natural and Agricultural Sciences, University of Pretoria

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Declaration

I declare that this thesis submitted by me to the University of Pretoria for the degree of PhD in Animal Science has not been previously submitted by any anyone for a degree at any other university.

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Preface

This thesis has been prepared under the supervision of Dr Carina Visser and Prof. Abubeker Hassen from the Department of Animal and Wildlife Sciences at the Faculty of Natural and Agricultural Sciences, University of Pretoria. It is structured into six chapters, including an Introduction, Literature review and manuscripts published or prepared for submission to peer-reviewed journals. Chapter One formulates the problem statement and motivation of the study. In Chapter Two, a literature review presents an overview of several aspects of indigenous goat production, focusing on alternative feeding and supplementation with fodder tree. The physiological adaptation of goats in harsh environments is also discussed. Chapters Three, Four and Five have been prepared in a manuscript format according to the guidelines of the specific journals. Chapter Three report results of a survey on smallholder goat production in the Namaacha and Moamba districts of southern Mozambique (published in the *Journal of Agriculture and Rural Development in the Tropics and Subtropics*). Chapter Four investigate the effect of seasonal variation on the composition of natural fodder in the Changalane district of Mozambique. This manuscript has been submitted for publication in the *Livestock Research for Rural Development Journal*. Chapter Five is the third and last scientific study on the impact of supplementation of *Moringa oleifera* (MO) and *Leucaena leucocephala* (LL) fodder tree on the production performance of indigenous goats in Mozambique; it has been published in the *Black Sea Journal of Agriculture*. The final chapter of the thesis gives conclusions and recommendations based on the research findings and a critical review of the current research. References from all chapters that have not been published yet, have been combined in a Reference list at the end of the thesis.

<u>Research outputs</u>

Peer-reviewed articles:

1. Mataveia, G.A., Garrine, C.M.L.P., Pondja, A., Hassen, A., Visser, C. 2018. Smallholder goat production in the Namaacha and Moamba districts of southern Mozambique. Journal of Agriculture and Rural Development in the Tropics and Subtropics, 119 (2) 31-41. https://doi.org/10.17170/kobra-2018112825
2. Mataveia, G., Garrine, C.M.P.L., Pondja, A., Hassen, A. Visser, C. 2019. Impact of supplementation of *Moringa oleifera* and *Leucaena leucocephala* tree fodder on the production performance of indigenous goats in Mozambique. Black Sea Journal of Agriculture, 2:93-102.

Conference presentations:

Mataveia, G., Garrine, C.M.P.L., Pondja, A., Hassen, A. Visser, C. 2018. Impact of supplementation of *Moringa oleifera* and *Leucaena leucocephala* tree fodder on the production performance of indigenous goats in Mozambique in Proceedings of the International Congress on Domestic Animal Breeding Genetics and Husbandry 2018 “ICABGEH-18” 26th to 28th of September, 2018, Antalya, Turkey.

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I am also thankful to the smallholder farmers for their participation, collaboration and willingness to participate in the survey conducted in the present study.

Finally, yet importantly, a special thanks to my beloved husband Carvalho Mendes Madivate for the encouragement and tireless support, and to my lovely children Fausio, Patricia, Gladys and Melvin. May they find here the expression of my sincere apologies for my absences and lack of care for them during the process of completing this study. I would also like to thank my family, especially my brother-in-law and Pastor Mário Getimane, who believed, encouraged, supported and prayed for me throughout my PhD studies.

Glory to God!

Dedication

I dedicate this thesis to my lovely grandchildren, Tairone Zua Moiane and Talita Febe Moiane

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Abbreviations

ADF	Acid Detergent Fibre
ADG	Average Daily Gain
ADL	Acid Detergent Lignin
BW	Bodyweight
Ca	Calcium
CP	Crude Protein
CO_2	Carbon Dioxide
CT	Condensed Tannins
DAGRIS	Domestic Animal Genetic Resources Information System
DM	Dry matter
DMD	Dry Matter Digestibility
DMI	Dry Matter Intake
FAO	Food and Agriculture Organisation of the United Nations
FAOSTAT	Food and Agriculture Organisation Statistics
FIAM	Applied and Multisectoral Research Fund
FNI	National Funds of Investigation
ESGPIP	Ethiopia Sheep and Goat Productivity Improvement Program
IAEA	International Atomic Energy Agency
G	Grams
GE	Gross Energy
INE	National Institute of Statistics
IVDMD	*In vitro* Dry matter digestibility
IVDOM	*In vitro* Dry Organic Matter
LL	*Leucaena leucocephala*
LW	Live weight
ME	Metabolisable Energy
MJ	Mega Joules
MO	*Moringa oleifera*
NDF	Neutral Detergent Fibre
NNP	Alternative Sources of Protein

NRC	National Research Council
P	Phosphorus
PENISA	*Plano Nacional de Investimento do Sector Agrário*
SADC	Southern African Development Countries
TLU	Tropical Livestock Unit

Abstract

This study investigated the potential benefit of introducing *Moringa oleifera* (MO) and *Leucaena leucocephala* (LL) leaves as supplementary feed resource for indigenous goats feeding systems in southern Mozambique. The study started with a description of smallholder goat production systems in three resource-poor districts of Mozambique and subsequently investigated the variation and seasonal fluctuations of natural fodder quality in the Changalane district throughout a year period. Thereafter, the effect of tree forage supplementation on growth and reproductive performance of Landim goats were evaluated by simulating a typical feeding system used in the study area.

In study one, a survey was conducted in three villages to collect data on indigenous goats and in smallholder husbandry practices in terms of feeding, health and reproduction management. Information from 45-smallholder goat keepers were recorded using a survey, which was complemented by interviews. Results showed that goats were raised under extensive systems, under free grazing. Tethering was a common management practice, with limited supplementation during the dry season. In general, during the dry season the natural pasture were scarcity and poor in quality and consequently does not sustained the energy and protein requirements of ruminants for maintenance and other functions. In study two, the eight key species that were consumed by the goats (namely *Sclerocarya birrea*, *Spirostachys africana*, *Dichrostachys cinerea*, *Flueggea virosa*, *Acacia nigrescens*, *Acacia nilotica*, *Panicum maximum* and *Morus alba*) were collected and analysed. Daily energy intake (4.27 ± 0.17 MJ/kg DM vs 3.71 ± 0.41 MJ/kg DM) and crude protein (CP) intake (92.83 ± 16.05 g DM/head/day vs. 59.38 ± 13.12 g DM/head/day) were higher in the rainy season than in the dry season. Daily intake of calcium and phosphorus did not show significant seasonal variations and were below the requirements levels for maintenance of a 20 kg bodyweight goat during the dry season and for the pregnant goat during both seasons. These results showed a need to supplement goats with energy, protein and phosphorus for maintenance, growth and reproduction during the dry season. In study three, the impact of supplementation with LL and MO on the growth and reproduction performance of indigenous goats were evaluated. Fifty-six goats were randomly divided into seven groups, with four castrated males and four females in each group. One group was used as the control group (animals grazing on natural veld without any supplementation), while first three groups were fed with LL and the other three groups with MO tree leaves, respectively. Compared to the control group, both treatments had a significant effect, irrespective of the level of supplementation in terms of overall body weight gain and the final body weight of the bucks. All female reproduction parameters measured for the supplemented groups were superior when compared to the control group. Findings of this study suggest the benefit of using LL and MO tree leaves as supplement for Mozambican goats to overcome the adverse effects of seasonal fluctuations in feed quality on their growth and reproductive performance.

Keywords: Communal, Extensive, Fodder trees, Indigenous Goats, Growth, Reproduction, Requirement, Small- scale, Supplementation

CHAPTER 1

GENERAL INTRODUCTION

Goats play a vital role in food security and contribute to improved livelihoods for various resource-poor communities (De Vries, 2008; Food and Agriculture Organisation of the United Nations [FAO], 2012; Hossain *et al.,* 2015). In Africa, goats are deeply entrenched in almost every African culture (Peacock, 2005), particularly within those communities that are not able to keep large livestock (such as cattle). Goats offer advantages in animal production as they have a relatively high productivity in harsh environments, use inexpensive feed resources, have a short reproductive cycle and have higher prolificacy when compared to cows (Madibela *et al.,* 2002; Peacock, 2005). These animals also have a beneficial effect on income generation and provide social and economic security to rural communities (Aziz, 2010).

Goat production has increased during the last decade and there are currently more than 1 billion goats, globally (Onzima *et al.*, 2018). Approximately 96% of these animals are meat goats and are found in developing countries in Asia and Africa (FAOSTAT, 2017). The African goat population has also increased over the last five years to approximately 422.7 million goats, representing 40.9% of the world's goats. Approximately 35 million of these goats are part of the Southern African population. Mozambique has around 3,94 million goats (11,26%), the fifth-highest amount in a ranking of 10 countries.

In Mozambique, goats are (one of) the most popular livestock species and play an important social role in smallholder farming systems (Mackinnon and Rocha, 1985; Cronjé, 1990; Garrine *et al.*, 2010). Of the total number of goats in Mozambique, smallholder farmers keep 97.66%, while only 2.27% are part of medium-scale systems and a negligible 0.07% is produced in intensive systems (National Institute of Statistics [INE], 2014). Goats are used for meat and contributed approximately 26 400 tonnes of red meat in 2017 (FAOSTAT, 2017). This contribution to the national economy is relatively small when compared to the 59.2 million tonnes produced by the beef industry (Plano Nacional de Investimento do Sector Agrário [PNISA], 2011). However, official figures commonly represent an underestimation of goat meat production, as most goats do not pass through formal marketing channels and abattoirs. Goats are mainly kept by smallholder farmers and are slaughtered for home consumption or sold in informal markets in order to raise money (Morgado, 2000; Boogaard and Moyo, 2015).

Goat production in Mozambique faces several challenges, of which fodder scarcity in the dry season is the most severe (Hove *et al.*, 2001). Goats depend exclusively on natural veld to meet their nutritional requirements, however, the seasonal fluctuations in forage availability and quality have been recognised as one of the leading causes of nutritional stress limiting animal production in (sub)tropical regions (Kawas, 2008). Due to nutritional stress, indigenous goats generally have low conception rates and litter sizes, as well as high rates of mortality and stunted growth of young animals (Mackinnon and Rocha, 1985; Cronjé, 1990). The poor physical condition of adult animals results in inferior growth performance, reduced carcass yield, low meat quality and an overall low productivity index (Faftine and Zanetti, 2010).

Supplementing goats with highly nutritive alternative feed sources has a positive effect on physiological functions (Oni *et al.*, 2010). Supplementation with lupin grain (Stewart and Oldham, 1986) and soybean meal or corn grain (Molle *et al.*, 1997), can improve reproduction efficiency by reducing the age at puberty and increasing ovulation rates. In addition, supplementation before mating can prevent a loss of body condition and increase the reproductive capacity of both ewes and goats (Blache *et al.*, 2008).

However, concentrate supplementation might not be feasible in low-income communities in Mozambique due to the high cost involved in the acquisition of conventional supplements. Therefore, there is a need to introduce cost-effective and sustainable alternative energy and protein sources. Such alternative feed resources may include locally available fodder trees, which represent an inexpensive source of protein and micronutrients (Mendieta-Araica *et al.*, 2011). Recently, there has been an increased interest in alternative protein sources from forage trees and shrubs that can also be used to feed goats. *Leucaena leucocephala* (LL) and *Moringa oleifera* (MO) are two of the alternative local sources that were identified with the potential to improve nutritional supply to goats (Muir and Massaete, 1996; Rubanza *et al.*, 2007; Oduro *et al*., 2008; Fasae *et al*., 2011; Mendieta-Araica *et al*., 2011; Moyo *et al*., 2012).

The advantage of forage trees over conventional concentrate supplementation is that the leaves can be readily harvested, sun-dried and used to prepare protein supplements by goat keepers. These can then be used to replace the more expensive standard supplements (Mendieta-Araica *et al.*, 2011).

Leucaena leucocephala is a drought-resistant leguminous tree (Devendra, 1993) and its nutritious leaves are readily consumed by Angora and Spanish goats (Yami *et al.*, 2000). It provides highly nutritious forage with a crude protein (CP) content as high as 29% (Damothiran and Chandrasekaran, 1982). In tropical agroforestry systems, it is commonly used for a variety of purposes, including as a mulch to improve soil fertility (Apuri *et al.*, 2018). It can also provide a balanced diet such as protein and carbohydrates for livestock and soil nutrients to companion crops when it is inter-cropped with cereals or with a pasture and forage crops (Robert *et al.*, 1996; Apuri *et al*., 2018). The potential benefits of LL on goat production have been reported in studies conducted in various tropical regions. Positive effects on body weight between gestation and kidding were reported in Nguni (Akingbade *et al.*, 2004) and Small East Africa goats breeds (Rubanza *et al.*, 2007) while average daily gain (ADG) were improved in Tanzania and in West African Dwarf goats (Fasae *et al*., 2011) in Nigeria and Landim goats from Mozambique (Muir and Massaete, 1996) due to LL supplementation.

MO is a protein supplement for livestock that can be grown quickly, even under drought conditions (Oduro *et al.*, 2008). Its leaves are nutritious, with CP content ranging from 23% to 40% (Marcu and Pharm 2005; Mendieta-Araica *et al.* 2011). This plant has also been reported to be rich in Vitamins A, B and C (Fahey, 2005; Gopalakrishnan *et al.*, 2016), and has a high level of calcium (Ca) (Rockwood *et al.*, 2013). It is rich in other minerals such as Potassium (K), Zinc (Zn), Magnesium (Mg), Iron (Fe) and Copper (Cu) (Kasolo *et al.*, 2010). Furthermore, it contains Selenium (Se) and Zn, which are components of antioxidant enzymes (Yazdanparast and Ardestani, 2007, Moyo *et al.*, 2011). In goats, the use of MO leaves improved ADG, which suggests its potential use as a low-cost alternative protein supplement (Moyo *et al.*, 2012).

However, such information regarding the use of these alternative feed resources for goats in Mozambique is scarce and has not been communicated to smallholder farmers.

Aim of the study

This study aims to investigate the potential benefit of introducing *Moringa oleifera* (MO) and *Leucaena leucocephala* (LL) leaves as supplementary feed resource for indigenous goats feeding systems in southern Mozambique.

Specific objectives

1. Describe smallholder goat production systems in two resource-poor districts of Mozambique.
2. Investigate the variation and seasonal fluctuations of natural fodder quality in the Changalane district throughout a year.
3. Evaluate the effect of tree forage supplementation on growth and reproductive performance of Landim goats.

CHAPTER 2
LITERATURE REVIEW

Introduction

Goats have been an important part of humanity since their domestication 10 000 years ago and they have since spread across the globe (Aziz, 2010; Hänke and Barkmann, 2018). Their roles and relative importance are not static but vary according to the agro-ecological zone, production system and socio-cultural context in which they are found (Kosgey *et al.,* 2008). Goats are one of the most important livestock species in developing countries (Simela and Merkel, 2008; Oluwatayo and Oluwatayo, 2012). Their importance hinges on the fact that they provide meat, hides, fibre and can be milked for home consumption (Mackinon and Rocha, 1985; Peacock, 2005; FAO, 2012). Goats are also used for socio-economic purposes, such as festive, religious and ceremonial occasions (Kosgey *et al.,* 2008; Rumosa Gwaze *et al.,* 2009; Garrine *et al.,* 2010). They play an important economic role, providing cash-flow and being an accessible source of credit in order to meet immediate social and financial obligations (Oluwatayo and Oluwatayo, 2012). Goats are therefore often described as the "village bank" (Maxwell, 1990; Oluwatayo and Oluwatayo, 2012).

Goats and sheep are preferred livestock species in dry areas due to their ability to convert poor quality pasture into good quality protein for human consumption (Ben Salem and Makkar, 2009). Additionally, because of their small size, goats allow the slaughter and consumption of the entire carcass by a family in few days, without the risk of deterioration due to the absence of conserving/cooling facilities in villages of developing countries (Gall, 1981; MacHug and Bradly, 2001; Peacock, 2005).

Goats are also quite portable due to their small size and can be carried or moved quickly if a family is forced to flee their home (MacHug and Bradly, 2001). For example, many goats trekked to safety during the fighting in Rwanda from 1990 to 1994 (Peacock, 2005) while many goats survived the floods in Mozambique during 2000 on makeshift floats (Peacock, 2005). Goats have the potential to decrease poverty in Africa due to the social role played in food security. Through the exchange of goats for agricultural labour and their contribution to increased food production, they could potentially lead to increased food security for many people in rural areas where crop production is their main activity and source of food (Boogaard and Moyo, 2015). Furthermore, food security can be increased through exploiting synergies between crops and livestock, by the use of manure and conversion of crop by-products by livestock (Udo *et al*., 2011; Herrero *et al.*, 2013; Smith *et al.*, 2013).

The Mozambican goat industry

Approximately 96% of the world's goat population is kept in developing countries, of which 64% are found in rural arid (38%) and semi-arid (26%) agro-ecological zones (Rumosa Gwaze *et al.*, 2009). The top-ten countries producing goat meat are all from Asia and Africa; indicating the importance of goat meat to people in resource-poor areas (Aziz, 2010). In Africa, goat meat production has increased from 1.1 million tonnes in 2008 to 1.3 million tonnes in 2017 (FAOSTAT, 2017); of which the majority is produced and consumed locally (within households) (Dubeuf *et al.,* 2004; Aziz, 2010). In Mozambique, the majority of goats (97.7%) belong to small-scale farmers and less than 1% are farmed intensively (INE, 2014). Goats are generally used for meat production (Morgado, 2000; Homann-Kee Tui *et al.*, 2013), however, most of this meat does not enter the formal market but is usually consumed locally and sold in informal markets (Morgado, 2000).

The two main types of goats found in Mozambique are the indigenous Landim and Pafuri breeds, which are both meat goat breeds (Garrine *et al.,* 2010). The Landim breed, also known as the Portuguese Landrace (Gall, 1996), is the most abundant and found throughout the country (Garrine *et al.,* 2010). The Pafuri breed is mainly limited to the Pafuri region, and north of the Gaza Province. The distribution of these breeds is shown in Figure 2.1.

Figure 2.1 The distribution of the two indigenous Mozambican breeds of goats (adapted from FAOSTAT, 2017)

The indigenous Landim breed is widely distributed throughout the country with little variation in size and adaptation. The breed is mostly found in semi-arid to sub-humid rainfall areas in the southern regions of the country (Gall, 1996; Garrine *et al.*, 2010). A typical Mozambican Landim doe is depicted in Figure 2.2. Male animals weigh, on average, 50 kg while the females are lighter at approximately 35 to 40 kg (Rocha *et al.*, 1990; Rumosa Gwaze *et al.*, 2009). The Landim from Tete Province seems to be smaller than in the south of Mozambique (Wilson *et al.,* 1989; Maciel *et al.,* 2004). The ADG from birth to three months and three to 12 months is 76 and 52 g/head/day, respectively, and the age at first mating and the inter-partum interval is 781 ± 319 (175) and 373 ± 167 (255) days, respectively (DAGRIS, 2007).

Figure 2.2 Typical Mozambique Landim does (Source: Maciel *et al.*, 2004)

The Pafuri breed resulted from the cross-breeding of male Boer goats from South Africa with Landim females. Garrine *et al.* (2010) confirmed this ancestry in a genetic characterisation study of Landim and Boer goats from Mozambique based on microsatellite markers. Although these goats have spread to other provinces, such as Maputo, no data is available regarding this distribution (Maciel *et al.*, 2004). The Pafuri breed has well-developed horns, lopped or semi-lopped ears with rounded tips, is bearded, has variable coat colours and short hair; as shown in Figure 2.3. The average mature body weight (BW) of an adult male Pafuri goat is 60 kg, and the females weigh approximately 43 kg (Mackinnon and Rocha, 1985; Wilson, 1991). There is limited data regarding the growth and reproductive parameters for this breed.

Figure 2.3 A typical Mozambique Pafuri doe (Source: Maciel *et al.*, 2004)

In addition to the two predominant breeds, the Boer goat was introduced in 1928 from the Northeast of the Transvaal (currently Limpopo Province) in South Africa into the Pafuri area in Southwestern Mozambique. This breed is maintained under semi-extensive to extensive management systems, generally in a (semi-) arid environment (Garrine *et al.,* 2010). This breed can also be found in other provinces of southern Mozambique, such as Maputo and Gaza (Garrine *et al.,* 2010). In Mozambique, indigenous breeds remain preferred due to their small size, superior adaptation traits (e.g. disease resistance, heat tolerance and survival) and high prolificacy and growth rates (Mackinnon and Rocha, 1985). The production parameters of the three goat breeds found in Mozambique are shown in Table 2.1.

Table 2.1 Production parameters of goats in Mozambique

Breeds	Body Weight (Kg)									
	Birth		Months: 3		Months: 6		Months: 12		Mature	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
Boer goats[1]	4	3.5	30-33	no	40-50	no	92	no	120-140	70-90
Landim[1,2]	2.5	2.3	9.6	8.2	14.3	12.3	22.0	21.6	50.0	35-40
Pafuri[3]	3	2.4	8.0	no	10.1	no	16.7	no	60.0	43.0

Source: [1]Mackinnon and Rocha (1985); [2]Gall (1996); [2]DAGRIS (2007); [2]Rumosa Gwaze *et al.* (2009); [3]Wilson. (1991). no: not available.

Goat production systems

In Southern Africa, small ruminant production systems are classified as traditional (communal) and commercial production systems. Most indigenous goats are kept in a small-scale production system in communal areas (Rumosa Gwaze *et al.,* 2009). The focus of this review will be on the communal system, which is a predominant (mostly traditional) production systems.

The traditional production system is characterised by informal labour (mostly from a family member); sometimes with low livestock numbers kept per unit area; minimal use of technology and limited use of inputs (Boyazoglu, 2002, Tavirimirwa *et al.*, 2013). The system is often hindered by land and water shortages, infections and predators (Rumosa Gwaze *et al.,* 2009). The smallholders do not have the skills and resources available for keeping records and there is uncontrolled breeding, therefore in breeding may occur. The traditional production system is further divided into two main production systems, namely the mixed crop-livestock system and pastoral production system (Peacock, 2005; Abegaz, 2014; Muigai *et al.,* 2017).

Mixed crop-livestock system

The mixed crop-livestock system is similar to the system that prevails in the most member states of the Southern African Development Communities Countries (SADC), including Mozambique (Rumosa Gwaze *et al.*, 2009). This system is characterised by raising a small number of goats together with other livestock species such as cattle, pigs and poultry. Livestock and crop cultivation are maintained as complementary ventures; animals provide manure that will be available for fertilising the soil for crop production while livestock in return benefit by feeding on crop residues during the time of feed shortages (Agossou *et al.,* 2017; Muigai *et al.,* 2017). This system is characterised by low managerial and financial inputs (Kebede *et al.,* 2012). It is a type of extensive farming system, with free-ranging, herding and tethering as the main feeding systems. This system is used by almost all pastoralists in Africa, where goats are frequently kept in mixed flocks with sheep. Children commonly herd goats, while the day-to-day management and care of young stock usually fall to women (Peacock, 2005). Under this system, animals graze communal land and animal herds owned by different families or individuals move from one area to another for grazing and water (Otte and Chilonda 2002; Asamoah, 2012; Muigai *et al.,* 2017). The goats graze over large areas of unwanted or marginal lands which are usually ill-suited for agricultural use (Devendra, 1983; Devendra and McLeroy, 1992; Muigai *et al.*, 2017).

In this system, low-skilled labour (often family members and children) are used as the primary goat handlers. They usually herd goats, sheep and cattle (as well as camels) together to graze wayside or waste vegetation. Management is limited to letting the goats out to graze during the day and confining them at night in enclosures, which are constructed using thorn bushes or wooden poles to protect them from theft and predation (Devendra, 1983; Devendra and McLeroy, 1992). There is no controlled breeding and no supplementary feeding or veterinary care for the animals, except for the extension services provided through government institutions (Rumosa Gwaze *et al.*, 2009). Due to a shortage of water and forage, malnutrition is the primary limiting factor for profitable production of small ruminants, particularly during the dry season (Rumosa Gwaze *et al.*, 2009). In Mozambique, 97% of the goats are raised under this extensive system (INE, 2010). Goat productivity and offtake rates from these systems are typically low. Shortages in nutrients and exposure to diseases, parasites, as well as challenging climatic conditions with frequent and prolonged droughts are responsible for slow growth, which leads to low productivity (Lebbie, 2004; Fantahun *et al.*, 2016).

Semi-intensive or agropastoral production system

The semi-intensive or agropastoral production system is typically encountered in urban and peri-urban areas (Agossou *et al.*, 2017). In this system, the goats typically graze two to four hours daily and then return to their paddocks in the evening. Usually, the farmers returning with the flock at night supply tree leaves and grass to feed them until the following morning, when they can graze them again (Devendra and McLeroy, 1992).

Tethering is a widespread practice of small ruminant management by smallholders in Southeast Asia, Central America and Southern African countries such as Mozambique (Mataveia *et al*., 2018), Zambia (Rumosa Gwaze *et al.*, 2009) and South Africa (Webb and Mamabolo, 2004). This feeding system is used to protect animals from theft and to prevent them from destroying crops and allows farmers to conduct other activities (Rumosa Gwaze *et al.*, 2009). Goats are often tethered in the morning and herded in the afternoon, when children have returned from school (Rumosa Gwaze *et al.*, 2009).

In this management system, water is provided when the goats are moved to shelter at night and limited (i.e. salt or mineral bricks), or no concentrates are provided. The only supplements, (which are provided infrequently) are household scraps, small quantities of grains or their by-products.

The physiological adaptation of goats to harsh environments

Goats are resistant to heat stress, droughts, food and water scarcity as well as diseases; they can maintain production and reproduction performance under harsh environmental conditions. This is in part due to their body size which enables efficient utilisation of low-quality forage and their tolerance to water scarcity and ability to retain superior thermoregulation (Visser, 2017; Darcan and Silanikove, 2018; Berihulay *et al.*, 2019). Climate change is expected to increase the frequency, intensity and length of droughts with a negative impact on rural areas, especially in sub-Saharan Africa where human populations mostly depend on rain for crop and livestock production (Muller, 2014). Mozambique is one of the countries in Southern Africa that is susceptible to drought, resulting in income reduction, decreased livelihoods and more poverty due to crop failure and a loss of livestock (Ncube *et al.*, 2018).

Furthermore, in Mozambique, the majority of goats are raised under extensive production systems (INE, 2010), which is commonly characterised by a shortage of natural pasture, water resources and extreme temperatures (Sölkner *et al.*, 1999; Mirkena *et al.*, 2010; Visser, 2017). However, indigenous goats have developed mechanisms, which allow them to adapt to high environmental temperatures and to achieve thermo-tolerance in extremely challenging environments (Mirkena *et al.,* 2010; Visser, 2017). These mechanisms include physical, physiological and biochemical changes, such as a reduced feed intake and metabolic heat production (Sarangi, 2018; Berihulay *et al.*, 2019).

There is ample evidence that livestock and indigenous breeds that are evolved in stressful tropical environments such as in Mozambique have a range of unique adaptive traits that enable them to survive and be productive and reproductive (Baker and Rege, 1994; Baker and Gray, 2004; Mirkena *et al.,* 2010). In addition, these goats feed primarily from browsing fodder, as potential sources of affordable feed for ruminants in developing countries. This is especially true during dry seasons, due to the ability of the available foliage to remain green and maintain its protein content, making these fodder potential sources of energy and protein to the goats (Olafadehan, 2013).

Adaptation to heat stress and drought conditions

Heat stress is an element that negatively affects livestock production and reproduction performance (Berihulay *et al.*, 2019). However, goats are considered less susceptible to heat stress than cattle because of their small metabolic size and their capacity to conserve water (Bayer and Feldmann, 2003; Salama *et al.*, 2014). Indigenous breeds of small ruminants in arid zones, such as the black Bedouin goats and Barmer goats herded in the deserts of Sinai (Middle East) and Rajasthan (India), can survive without drinking water for several days, often only drinking water once every four days (Silanikove, 2000; Bayer and Feldmann, 2003). Desert goats have been reported to have a superior ability to withstand dehydration, and are considered among the most efficient ruminants in this regard (Silanikove, 1994). The biological mechanisms that enables desert goats to cope with droughts depend on their ability to withstand dehydration and to minimise water losses via urine and faeces (Silanikove, 2000; Berihulay *et al.*, 2019).

The animals can have large, small or dwarf bodies, which help them to regulate water loss and heat gain in scorching environments (Cain *et al.*, 2006; Sarangi, 2018). Their colour adaptation of the integumentary system also helps them to reflect heat (Sarangi, 2018). Various morphological traits, such as body size and shape (Silanikove, 2000), coat and skin colour, hair type, and fat storage aid goats in their superior adaptation to harsh environments (Chedid *et al.*, 2014; Salama *et al.*, 2014; Sarangi, 2018). Typically, dark-coated animals receive more heat loads than light-coloured ones (Naskar *et al.*, 2012) and the light-coloured coat is deemed superior in tropical regions (Goodwin *et al.*, 1997). Additionally, skin pigmentation provides protection for deep tissues against solar short-wave radiation in tropical regions (Hillman *et al.* 2001). Interestingly, goats with long hair tolerated radiant heat better than short-haired goats (Acharya *et al.*, 1995).

Reducing feed intake is another way to decrease heat stress in warm environments because the heat increment due to feeding, especially in ruminants, is a significant source of heat production (Kadzere *et al.*, 2002; Attia, 2016). Goats are one of the ruminant browsers that suffer least during droughts (Kay, 1997). This is due to their ability to survive on a diet constituted normally of browsing, which is least affected by the drought (Mikena *et al.,* 2010). If the drought persists, the carrying capacity of the veld will inevitably fall but it will still be able to support goats longer than other herbivores, such as sheep and cattle, due to the goats' capacity to reduce their metabolism and to maintain this low metabolic requirement (Mirkena *et al.,* 2010; Visser, 2017). The ability of goats to survive prolonged periods of water deprivation also allows them to graze far from watering sites and to exploit available pastures optimally.

Adaptation to feed scarcity

The adaptation of goats during periods of feed shortage can be via the following processes: low metabolic requirements, their capability to decrease their metabolism, increased digestive proficiency, an ability to utilise high-fibre feed and the deposition of nutrients in the form of fat as feed reserve (Mirkena *et al.*, 2010).

Goats develop low metabolic requirements during a period of shortage of natural pasture (Visser, 2017). They can adjust to a low energy intake by reducing their energy metabolism (Silanikove, 2000; Daramola and Adeloye, 2009) and are thus able to maintain their body weight in times when food is scarce. A low metabolic requirement is an advantage if the quantity and quality of vegetation are inadequate. The improved temperate breeds are more productive than indigenous tropical breeds if ample high-quality feed is available; however, they lose weight and have increased mortalities when the environment becomes challenging and they have to graze on poor quality veld. However, under the same circumstances, adapted indigenous animals still grow and other physiology processes continue, such as reproduction and milk yield (Mirkena *et al.,* 2010). The adapted tropical animals recycle nutrients more efficiently than improved temperate breeds and their metabolism is reduced when the animal is losing weight (Bayer and Feldmann, 2003).

The ability to reduce their metabolism permits goats to survive even after prolonged periods of severely restricted food availability (Mirkena *et al.,* 2010; Visser, 2017). Their selective browsing behaviour (Silanikove, 2000) and an efficient digestive system allow the goats to maximise food intake and scarce nutrients (Daramola and Adeloye, 2009). Silanikove (2000) showed that the intake and digestibility of low quality foods can be increased by adding urea to that diet. Therefore, there is a favourable association between the improved reutilising rate of urea and better digestion of such food in desert goats.

Silanikove (2000) had reported the digestive efficiency of indigenous goats and their capability to utilise high-fibre feed. Goats have superior digestive efficiency compared to sheep and cattle when using high-fibre low-quality forages because of the longer mean retention time in the rumen (Devendra, 1990; Tisserand *et al.,* 1991). They can also eat more tannin-rich material and can thus utilise plant species that cannot be consumed by sheep (Silanikove, 2000; Darcan *et al*., 2017). Goat breeds that are indigenous to semi-arid and arid areas can utilise low-quality high-fibre feed more efficiently than their exotic equivalents and also outperform indigenous sheep and cattle breeds (Silanikove *et al.,* 1993). For instance, indigenous desert black Bedouin goats outperformed Swiss Saanen goats in terms of digestive efficiency when fed on roughage diets in both controlled environments (Silanikove *et al.,* 1993) and under natural conditions in a harsh environment (Brosh *et al.,* 1986).

Ruminants accumulate energy in adipose tissues when the quality and quantity of feed is sufficient, and mobilise it to meet energy requirements during periods of shortage (Nigussie *et al.,* 2000; Ermias *et al.,* 2002). In a tropical environment the rainy seasons alternate with dry seasons. The dry seasons are generally long and characterised with low quantity and quality veld. The capacity to accumulate fat during the rainy seasons for its subsequent use for maintenance and biological functions (like pregnancy and lactation) in the dry season is an essential strategy for survival (Nigussie *et al.,* 2000).

The nutritive requirements of indigenous goats

The nutritional needs of meat goats vary according to their age, weight, stage of growth and physiological status. In tropical Africa, there are many breeds of goat, each adapted to particular environmental conditions with differing nutritional requirements (Aregheore *et al.,* 1992; National Research Council [NRC], 2017). In general, a goat needs a daily intake equal to approximately 3% of its body weight for maintenance (Kearl, 1982; NRC, 2007; Rashid, 2008). However, the efficient utilisation of nutrients depends on the ratio of energy to protein (Faftine and Zanetti, 2010). Equally, the daily feed intake of goats is influenced by percentage of DM in the feeds ingested, which ranges from 12-35% in forage and 86-92% in hay and concentrates (Rashid, 2008).

In order for a goat to meet maintenance requirement for a mature goat (growth of 100 g/day), the total dietary metabolisable energy (ME) and CP should be 7.76 MJ/day (megajoules per day) and 98.13 g/day, respectively (Rahman *et al.*, 2014). Additionally, Ca and P should be included at 1.5 g/kg and 0.072 g/kg, respectively, in mature African breeds raised under tropical environments (Pamo *et al.*, 2007).

Feeding MO leaves improved the growth performance of goats, which indicates that MO could be used as an alternative protein supplement in goat production and can be seen as a good and low-cost alternative to meet the nutritive requirements in the diet balance (Sultana *et al.*, 2015; Abd El-Hack *et al.*, 2018; Ikyume *et al.*, 2018; Yusuf *et al.*, 2018).

Metabolisable energy (ME)

Goats need energy for maintenance, productive and reproductive functions (Rashid, 2008). Energy deficiency decreases kid growth, and has an adverse effect on reproduction, such as delayed puberty, reduced fertility in does and bucks and decreased milk production (NRC, 2007; Blache *et al.*, 2008; Faftine and Zanetti, 2010). It also lowers resistance to parasites and disease and, in severe cases, causes death due to starvation (Vincent, 2018).

Metabolisable energy is measured in MJ per kilogram of feed DM (Vincent, 2018). It is usually calculated from the dry matter digestibility (DMD) of feed using an appropriate equation (Standing Committee on Agriculture and Resource Management, 1990). Metabolisable energy is the unit used to measure the energy content of feeds and is the amount of energy remaining after losses in faeces, urine and gases (methane and carbon dioxide) produced by ruminal microbes fermenting the feed. Metabolisable energy is measured in MJ per kilogram of feed DM (Vincent, 2018). The most significant loss of energy during digestion is lost via faeces. Dry matter digestibility is the proportion of DM consumed that is not excreted in the faeces and it is expressed as a percentage (Vincent, 2018).

Indigenous kids ranging from 5 to 25 kg in BW require between 5.39 ± 1.49 to 9.74 ± 2.57 MJ to gain one kilogram of BW (Resende *et al.*, 2018). Good quality roughages furnish about 8.4 MJ ME per kg of DM. It might be necessary to supply roughage-concentrate mixed rations in order to increase the energy content of the diet to 10.5 or 12.6 MJ ME/kg DM when feeding early-weaned kids or high-producing dairy goats. It is commonly acknowledged that the concentrate to roughage ratio is an essential factor to be considered for improving feeding efficiency (Liu *et al.*, 2005). This however is challenging, as no data is available on how efficiently indigenous goats utilise grain-less diets (common in resource-poor communities) with different ratios of concentrate and roughage (Sebsibe, 2006). Moreover, the estimation of these values require rumen degradability but degradability data of these feedstuffs using indigenous goats are not documented in Mozambique. Similarly data related to the DM and neutral detergent fibre (NDF) degradability of different feeds in goats and changes in the rumen environment are lacking. This poses a challenge as these parameters directly influence the nutritive value of feedstuffs (Van Soest, 1994; Juárez *et al.*, 2004; Woyengo *et al.*, 2004).

The energy requirements of goats and sheep vary widely and are the result of their status and the stage within the production cycle. Pregnant sheep and goats have more than 1.5 times their maintenance requirements. Lactating females may have even higher energy requirements, at around 2.5 times the usual amount (Deminicis *et al.*, 2009). Inappropriate grazing management, rangeland fires and droughts associated with poor management of said rangelands cause limited availability of quality fodder in communal areas (Timberlake and Jordão, 1985; Rumosa Gwaze *et al.*, 2009).

However, some researchers reported that specific crop residues can be used to replace the concentrate feeds in goat diets without reducing performance; they are also economically viable (Meffeja *et al.*, 2000; Morales *et al.*, 2000; Malau-Aduli *et al.*, 2003). Cereal grains (wheat, barley, corn, and oats) are sources of energy, whereas pasture, good-quality hay and browse are good sources of protein and minerals (Schoenian, 2006).

Crude protein

The tissues of the body consist mainly of water and protein. Protein contains the nitrogen (N) needed by the ruminal microorganisms to manufacture their protein consisting of amino acids, which are later digested by the goats (Vincent, 2018). The amount of protein provided for small ruminants is more important than its quality due to their capacity to resynthesise fraction of protein intake, as the quantitative and quality needs of proteins can be corrected by ruminal micro-organisms. This dietary protein is digestible and proteins have an important role in the constitution of tissues and some hormones (Rashid, 2008; Deminicis *et al.*, 2009).

If a goat's protein intake is too low, the digestion of carbohydrates will slow down. Insufficient consumption of proteins will reduce the supply of rumen degradable protein, reduce fermentation of fibrous feeds in the rumen, lower consumption of feed, resulting in weight loss, anaemia and low resistance to diseases. This has negative consequences on the growth rate, leading to abortion, insufficient milk production, decreased fertility and a generally poor condition of kids and adults (Deminicis *et al.*, 2009; Vincent, 2018).

The percentage of CP in the feed does not refer to how much protein is available to the animals, as some protein is unavailable when bound to the fibres of the feed due to heat damage (McDonald *et al.*, 2002; Vincent, 2018). This is true for feeds like crop residues. Whereas other feedstuffs such as cereals, oil seeds and agro-based by-products have between 20 and 50% of proteins in their chemical composition.

In general, oil seed and agro-based by-products used for the extraction of edible oil, pies, soya, peanut, sunflower, cotton, soybean, cottonseed, corn, barley peas or oats have generally around 20% CP while the oilseed cakes have around 50% CP values (Rashid, 2008; Harjanti *et al.*, 2012; Rahman *et al.*, 2014). There is another option - to use animal sources, such as fishmeal and even the use of non-protein nitrogen (NPN) sources as is the case with urea (Resende *et al.*, 2018). It is recommended that indigenous kids weighing from 5 to 25 kg should ingest 4.45 ± 1.24 g CP/kg of BW to meet their protein requirements for maintenance (Resende *et al.*, 2018).

Mineral calcium (Ca) and phosphorus (P)

Mineral elements essentially represent 4–5% of the BW of adult animals. Minerals play an important role in various tissues for metabolic processes, the acid-base equilibrium, cellular permeability and maintenance of osmotic pressure (Baruselli, 2010; Gomes *et al.*, 2011).

Mineral elements are classified according to their concentration in the animal body; the mineral macroelements are in the range of 0.01% to 0.9% of live weight. Macrominerals consist of seven minerals, namely Calcium (Ca), Phosphorus (P), Potassium (K), Magnesium (Mg), Sodium (Na), Sulfur (S) and Chlorine (Cl) (Teixeira, 2001; Rashid, 2008).

At the same time, mineral deficiencies can depress herbage intake, forage digestibility and ultimately decrease livestock production efficiency (Khan *et al.*, 2007). The availability of minerals for metabolic processes are influenced by several interactions among these minerals, and this might result in deficiencies in terms of maintenance requirements, and may even lead to metabolic disorders (NRC, 2007).

Calcium and P are the two most essential minerals when feeding meat goats and they require vitamins A, D, E and K to produce B vitamins in their rumens (Schoenian, 2006). In this review, the focus will be on two minerals, Ca and P, due to their importance in bone development in young animals and milk production. The content of these elements also vary significantly between pasture species and can even show seasonal variations in uptake (Miles and Manson, 2000).

In subtropical and tropical areas, forages rarely provide all the mineral requirements of grazing ruminants (McDowell *et al.*, 2000). Forage Ca concentrations increase significantly with the maturity of forage plants from dry to wet seasons (Mpofu, 1996; Ashraf *et al.*, 2005). However, the P concentration of forage plants declines markedly with advancing maturity due to the mobility capacity of minerals within the plant, where P is considered to be a highly mobile element (Khan *et al.*, 2005; Ndebele *et al.*, 2005).

Bone tissue grows rapidly in young animals in comparison to adults (Lawrence and Fowler, 1997). More than 90% of Ca and 80% of P that are present in the animal are found in the bone tissue (Underwood and Suttle, 1999). This may explain the observation of an increase in the deposition of these two minerals in goats with BWs below 20 kg (Gomes *et al.*, 2011), specifically in Moxotó kids (Araujo *et al.*, 2010) and Canindé kids (Souza *et al.*, 2010) with BWs ranging from 15 to 25 kg. These kids were observed to have increasing concentrations of these minerals with an increase in their BWs (Bellof and Pallauf, 2007).

The animal requirement for Ca and P is often expressed as the Ca:P ratio, which should be in the range of 1:1 to 2:1, depending on the type of animal (McDonald *et al.*, 2002). Bone tissue has a Ca:P ratio of 2:1, which is recommended for healthier bone structure (AFRC 1991; Rashid, 2008). Minimum requirements of the indigenous goat breeds found in Mozambique are shown in Table 2.2.

Table 2.2 The minimal requirements of indigenous goats (NRC, 2017)

	BW (kg)	BW gain (g/day)	ME (MJ/day)	CP (g/day)	Ca (g/day)	P (g/day)
Mature does maintenance	20	0	4.02	36	1.2	0.8
	30	0	5.44	49	1.4	1.0
	40	0	6.74	61	1.7	1.3
Mature does breeding	20	0	4.39	40	1.3	0.9
	30	0	5.94	54	1.5	1.1
	40	0	7.41	67	1.8	1.4
Mature does early gestation with single kid: BW=2.3 to 5.2 kg	20	9	5.10	59	3.4	1.7
	30	13	6.86	78	3.7	2.0
	40	16	8.41	94	3.9	2.3
Mature does early gestation with twin kids: BW=2.1 to 4.8 kg	20	10	5.77	71	5.0	2.4
	30	21	7.61	92	5.3	2.8
	40	26	9.29	110	5.6	3.8
Mature does late gestation with single kid: BW=2.3 to 5.2 kg	20	38	7.53	88	3.5	1.9
	30	51	9.92	114	3.9	2.2
	40	63	12.05	136	4.1	2.5
Mature does late gestation with twin kids: BW=2.1 to 4.8 kg	20	66	9.33	108	5.1	2.5
	30	85	12.09	137	5.4	2.8
	40	106	14.60	172	6.0	3.4
Male indigenous local breed	20	0	4.27	43	1.3	0.9
	30	0	5.77	59	1.6	1.2
	35	0	6.49	66	1.7	1.3
	40	0	7.20	73	1.8	1.4

The limitations of natural pasture

In Southern Africa, grassland quality and quantity are highly variable and represent the main limitation of livestock production (Olafadehan and Adewumi, 2009). Bakshi and Wadhwa (2007) and Kalundi *et al.* (2007) reported decreases of CP levels below 8% in dry, mature tropical grasses used for feeding livestock and a low content of CP, minerals and vitamins and an increase in lignin content, responsible for the decrease of the overall digestibility of veld grasses (Faftine and Zanetti, 2010).

The shortage and seasonal quantity and quality of natural pasture become critical during the dry season and this has a negative impact on voluntary intake and digestibility of fodder, leading to reduced productive and reproductive performance of goats (Olafadehan and Okunade, 2018). Under dry conditions, grazing animals are often unable to satisfy their nutritional requirements, especially during certain physiological phases like gestation and lactation (Raghuvansi *et al.,* 2007; Ben Salem and Smith 2008; McSweeney *et al.,* 2010).

The nutritive values of natural veld (grasses, shrubs and tree) vary between species; these variations in CP, Ca and P are summarised in Tables 2.3, 2.4 and 2.5. The chemical composition of Southern African grass species shows a variation of CP content which varies from 2.4% in S*etaria verticillata* (Keba *et al.*, 2013) to 9.0% in DM of *Panicum maximum* (Chiphwanya, 2007). Calcium content ranges between 0.03g in DM of *Digitaria sp* (Sadiq *et al.,* 2015), to 1.10g in DM of *Bothriochloa insculpta* (Tesfera *et al.,* 2009) while the nutritive values of P vary from 0.02g in *Aristida sp* (Sultan *et al.,* 2008) to 0.32 g in *Panicum maximum* (Rusdy, 2014).

Table 2.3 Nutrient value of common species of grasses in tropical and semi-arid zones

Species	CP	Ca	P
Grass	**%**	**g/100g/DM**	
Cenchrus ciliaris	7.3[1]	0.33[1]	0.09[1]
Digitaria sp	5.6[1]	0.03[2]	no
Eragrostis curvula	6.2[1]	0.23[3]	0.15[3]
Themeda triandra	7.3[1]	0.29[5]	0.08[5]
Heteropogon contortus	6.1[1]	0.20[6]	0.04[6]
Aristida sp	5.4[1]	0.45[6]	0.02[6]
Bothriochloa insculpta	5.8[1]	1.10[7]	0.30[7]
Setaria verticillata	2.4[1]	no	no
Cynodon dactylon	8.8[4]	0.23[3]	0.25[3]
Pennisetum purpureum	8.5[4]	0.36[8]	0.17[8]
Hyparrhenia sp	8.0[4]	no	No
Panicum maximum	9.0[4]	0.68[9]	0.32[9]

GE - Gross energy; CP - Crude Protein; Ca - Calcium; and P -Phosphorus; no: not available

Source:[1]Keba *et al.* (2013); [2] Sadiq *et al.* (2015); [3]Bredon *et al.* (1987); [4]Chiphwanya (2007); [5]Ayanda (2013); [6]Sultan *et al.* (2008);[7]Tesfera *et al.* (2009); [8]Adjolohoun (2008); [9]Rusdy (2014)

The nutritive values of shrubs found in Southern Africa are presented in Table 2.4. Crude protein content varies from 6.09% in *Maytenus senegalensis* (Dambe *et al.*, 2015) to 16.5% in *Acacia nilotica* (Aganga *et al.*, 2000). Calcium nutritive value varies between species from 0.15 g in DM of *Spirostachys Africana spp* (Colgan, 2015) to 4.85 g in DM of *Acacia nigrescens* (Dambe *et al.*, 2015) while P varies from 0.07 g in DM of *Acacia tortilis* (Dambe *et al.*, 2015) to 0.60 g in DM of *Spirostachys Africana spp* (Colgan, 2015).

Table 2.4 Nutrient composition of leaves of shrubs species

	CP	Ca	P
Species		**%**	
Acacia mellifera F L	14.5[1]	2.26[1]	0.12[1]
Grewia bicolor FL	13.1[1]	1.27[1]	0.22[1]
Maytenus senegalensis M L	6.09[1]	4.16[1]	0.16[1]
Colophospermum mopane	13.4[1]	1.15[1]	0.16[1]
Acacia nigrescens ML	10.9[1]	4.85[1]	0.09[1]
Acacia tortilis ML	10.2[1]	2.39[1]	0.07[1]
Acacia nilotica ML	16.5[2]	0.93[2]	0.14[2]
Dichrostachys cinerea FL	12.9[2]	0.65[3]	0.13[3]
Spirostachys Africana spp FL	no	0.15[4]	0.60[4]

GE- Gross energy; CP- crude protein; Ca- calcium; P- Phosphorus; ML-Mature leaves and FL-Fresh leaves

Source:[1]Dambe *et al.* (2015); [2]Aganga *et al.* (2000); [3]Marius (2016); [4]Colgan (2015); no: not available.

It is clearly indicated that most browse species can be used as high quality feeds for livestock, not only in the dry season where quality feed is scarce but also throughout the year. The high nutrient content of the browses, especially CP, is generally higher than the recommended requirement for all classes of indigenous goats (36 to 176 g/day, for mature doe maintenance and does in late gestation with twin kids, respectively) (NRC, 2017). Most browse species exceed the 7% CP requirement that is necessary for ruminants to provide the ammonia required by rumen microorganisms in order to support optimum microbial activity (Njidda, 2010). The high CP content of many browse species is well documented and one of the unique traits of shrubs compared to most grasses (Kubkomawa *et al.*, 2015), and also one of the main reasons for its perceived superiority.

The contents of the essential nutrients (CP, Ca and P) in tree species are summarised in Table 2.5. Crude protein content varies between species from 6.08% in *Combretum imberbe* (Dambe *et al.*, 2015) to 24.66% in DM of *Gliricidia sepium* (Anis *et al.*, 2016). Calcium content ranges between 0.08% in DM of *Sclerocarya birrea* (Colgan, 2015) to 3.01% in DM of *Combretum* *hereroense* (Dambe *et al.,* 2015) while the nutritive values of P vary from 0.04% in *Boscia albitrunca to* 2.1% in *Sclerocarya birrea* (Colgan, 2015).

Table 2.5 Nutrient value of common species of fodder tree in DM in tropical and semi-arid zones

Species	**CP**	**Ca**	**P**
Tree	%	**g/100g/DM**	
Combretum hereroense FL	7.18[1]	3.01[1]	0.08[1]
Lonchocarpus capassa FL	23.9[1]	0.61[1]	0.29[1]
Combretum apiculatum FL	15.1[1]	0.63[1]	0.27[1]
Peltophorum africanum FL	11.5[1]	0.70[1]	0.15[1]
Euclea schimperi ML	7.30[1]	1.32[1]	0.05[1]
Combretum imberbe FL	6.08[1]	1.38[1]	0.09[1]
Pappea capensis FL	8.01[1]	1.76[1]	0.09[1]
Boscia albitrunca ML	11.2[1]	1.50[1]	0.04[1]
Colophospermum mopane	13.4[1]	1.15[1]	0.16[1]
Combretum apiculatum	15.1[1]	0.63[1]	0.27[1]
Ficus thonningii	14.37[2]	0.21[7]	0.19 [7]
Ziziphus mucronata	9.82[3]	0.67[3]	0.09[3]
Terminalia sericea	9.82[3]	0.75[3]	0.09[3]
Medicago sativa	14.0[4]	No	No
Sclerocarya birrea	10.19[5]	0.08[5]	2.1[5]
Gliricidia sepium	24.66[6]	1.88[6]	0.24[6]

CP - crude protein; Ca - calcium; P - Phosphorus; ML - Mature leaves and FL - Fresh leaves

Source: [1]Dambe *et al.* (2015); [2]Balehegn and Hintsa, (2015); [3]Marius (2016); [4]Aganga *et al.* (2000); [5]Colgan (2015); [6]Anis *et al.* (2016); [7] Mbatha and Bakare (2018); no: not available

The crude protein content of fresh leaves was highest in *Gliricidia sepium* and *Lonchocarpus capassa,* with 24.66% (Anis *et al.*, 2016) and 23.9% (Dambe *et al.*, 2015), respectively. It was lowest in *Combretum imberbe* with 6.08 % (Dambe *et al.*, 2015). Similar to the leaves of shrubs, the fodder tree browses can be used as supplements due to their higher protein content of 12-30 % DM compared to mature grasses with a protein content of 3-10% DM (Boitumelo, 2000). The differences reported in nutritive values of grass and browse forages have been reported previously and are due to various factors, including soil type and climate, plant differences, growth stage and season (Njidda 2010; Abdullah *et al.*, 2013).

Overcoming limitation of natural pasture through supplementation of goats

Extensively reared livestock in tropical and semi-arid regions are mainly characterised by indigenous breeds where the nutritional needs of animals are exclusively dependent on natural pastures (Ben Salem, 2010). Thus, natural veld represents the main supply of nutrients for goats in a region affected by seasonality and prolonged periods of drought in the dry season (Ben Salem, 2010; Marques *et al.,* 2014).

Due to the incapability of natural pastures to provide the necessary nutrient requirements to goats, supplementary feeding is required to maintain production levels (Mapiye *et al.,* 2006). A continuous supply of feed throughout the year should lead to improved and sustainable livestock production - specifically during the dry season (Marques *et al.,*2014*;* Marius, 2016).

The deficiency of adequate year-round feed resources contributes to low animal production in tropical, semi-arid and arid regions in the world (Ben Salem and Smith, 2008; Kawas *et al.,* 2010). Protein is the primary limiting nutrient in dry seasons grazing (Pimentel *et al.*, 2011) and mineral deficiencies can depress forage digestibility and herbage intake, which can ultimately decrease live weight gain and livestock production efficiency (Khan *et al.*, 2007). Crude protein and minerals such as Ca and P should be supplemented in the dry season in Southern Africa (Pimentel *et al.*, 2011; Dierenfeld *et al.*, 2014).

Alternative sources of protein and mineral supplements are necessary to counteract animal weight loss during the dry season (FAO, 2004). This is important for animals to recover weight lost during the dry season quickly with the onset of the rainy season through compensatory growth (Kasale, 2013). Natural pasture sources are particularly preferred because commercial concentrate feeds are expensive and unaffordable for the majority of smallholder goat farmers (Kasale, 2013; Sultana *et al.,* 2014; Babeker and Bdalbagi, 2015). Therefore, it is necessary to investigate the use of locally-available alternative feed resources and incorporate these in sustainable supplementation strategies, together with identifying new technologies to optimise the use of these alternate feedstuffs (Ben Salem, 2010).

Fodder trees and shrubs present a potential source for ruminates supplementary feed as they are able to provide protein, vitamins and the relative amount of mineral elements, which are mostly lacking in grass (Marius, 2016). Unlike most grass species, change in the CP content of fodder trees with leaf maturity, even when they dry and fall to the ground, is very small (van Tol, 2004). Through the increased supply of nutrients (mainly energy and protein) to rumen microorganisms, fodder trees improve ruminal fermentation and microbial protein supply to the host animal and hence improve the performance of ruminants (Osuji *et al.*, 1995).

Woody plants, especially those that belong to the genus Acacia, are adapted to the low humidity environment and are widely spread in Southern Africa, especially in Namibia, Botswana, Zimbabwe, South Africa and Mozambique. Acacia species and *Dichrostachys cinerea,* for example, have foliage that grows in the dry season and the pods and fruits, which are formed, are consumed by goats (Mlambo and Mapiye, 2015). In Zimbabwe, the use of tree pods as dry season protein supplements has been evaluated by Sikosana *et al.* (2002); Mlambo *et al.* (2004) and Smith *et al.* (2005). These authors found that *Acacia nilótica and Dichrostachys Cinerea* fruits were beneficial for goat N-nutrition as supplements during the dry season and increased milk yield of goat. In Mozambique, several researchers (Seijas *et al.*, 1994; Muir and Massaete, 1996; Nguluve and Muir, 1999; Pimentel *et al.,* 2011) showed that multipurpose legume trees as a source of low-cost protein in the diets of ruminates resulted in body condition maintenance and substantial increase in ADG in the dry season. Goats and sheep supplemented on grass with *Leucaena leucocephala* mixed pastures increased ADG by 27.8% and 48.8%, respectively, as compared to non-supplemented small ruminants (Pimentel *et al.,* 2011).

Conventional supplementation includes feed licks or blocks, agro-industrial by-products, ionophores, non-protein urea and energy and protein concentrates. In general, the focus will be on supplementing agro-industrial by-products. The main advantages and disadvantages of different agro-industrial by-products will be discussed in more detail. Conventional supplementation, such as ionophores, non-protein nitrogen (urea), energy, and protein concentrates are seen as the solution to limited availability of good quality fodder. However, its implementation by small-scale farmers, particularly in developing countries in Africa, is insignificant as these alternatives represent an expensive solution (Babeker and Abdalbagi, 2015). This aspect prompted research on alternative fodder tree species as a sustainable source of supplementation.

Agro-industrial by-products

Several studies (Ben Salem, 2010; Girma, 2010; Tedla, 2014) showed that supplementing ruminants with agro-industrial by-products or concentrates enhanced the utilisation of low-quality roughages and improved livestock performance. Additionally, the utilisation of agro-industrial by-products plays an essential role on smallholder dairy farms for the supply of ME and CP, which are vital components in feeding dairy cattle for optimum productivity (Lukuyu *et al.*, 2011; Kabi *et al.*, 2013). However, the utilisation of agro-industrial by-products by the rural community is constrained because of low availability and higher cost (Adugna, 2009; Ben Salem, 2010; Yinnesu and Nurfeta, 2012). The production and supply of most agro-industrial by-products are irregular and localised around the main urban centres, making them inaccessible and unaffordable for smallholders as a supplement to low-quality diets (Adugna, 2009). Therefore, it has become necessary to investigate economical ways of supplementation using alternative fodder tree supplements that are available in rural households. The multipurpose benefit of fodder trees is well recognised as a potential feed resource that can be used to supplement a roughage-based diet (Kass *et al.*, 1992; Mapiye *et al.*, 2009).

Sikiru and Makinde (2018) performed research on supplementing goats under a basal diet, with extensive grazing and a concentrate diet produced using predominant crop residues and by-products (maize bran, 49%, rice bran, 49%, groundnut cake, 1.50% and vitamin, 0.50%). They reported a significant difference for the weaning weights between the control group without supplementation, and second group with concentrate diets in addition to extensive grazing and third group supplemented with cowpea haulms and millet straw as basal diet and concentrate in addition to extensive grazing, with values of 5.05 kg, 7.16 kg and 7.38 kg, respectively. Likewise, the ADG was 25.00 g/head/day, 44.25 g/head/day and 44.00 g/ head/day for the goats under control group, second and three groups respectively.

Fodder trees

Goats commonly make use of leaves (browsing) in addition to grazing grasses; this is even more customary in humid, tropical countries (Morand-Fehr, 2005). At present, research indicate that a large number of fodder tree leaves can be included in goat diets, as confirmed in several studies that reported levels of intake and *in vitro* digestibility of the fodder tree leaves (Bais *et al.*, 2002; Brij and Murdia, 2002; Bamikole *et al.*, 2003). The ease with which the fodder trees' leaves can be harvested, dried and prepared as protein supplements, is a huge advantage and these can then be used to replace conventional ingredients with cheaper and nutritious supplements (Mendieta-Araica *et al.,* 2011). Therefore, fodder trees can be introduced as cheap and sustainable alternative energy and protein supplements and can be grown locally, with the limited resources available in these communities.

The utilisation of fodder trees and shrubs as supplements could be a potential strategy to supply good quality, accessible supplements for resource-poor livestock farmers during the challenging periods of the year. They represent an effective and cheap source of protein and micronutrients (Moyo *et al.*, 2012). Among these tree forages are *Moringa oleifera* (Damor *et al.*, 2017) and *Leucaena leucocephala* (Fasae *et al.,* 2011) and they are seen as trees with a beneficial effect on goats.

The use of available fodder trees as supplements are viable economic alternatives for smallholder farmers compared to purchased concentrates or agro-industrial by-products in many regions of the tropics (Getu, 2006; Place *et al.*, 2009; Njidda, 2010). The fodder trees have high CP content, ranging from 10 to 31.2% on a DM basis (Simbaya, 2002; Osti *et al.*, 2006; Chepape *et al.*, 2011; Fadiyimu *et al.*, 2011; Kabi and Lutakome, 2013). This is adequate to ameliorate the nutritional deficiencies of natural pasture, making them an important source of supplementation for ruminants (Getu, 2006; Kanani *et al.*, 2006). *Gliricidia sepium*, LL, *Sebania sesban*, MO, *Acacia angustissima,* and *Medicago sativa* are multi-purposed and locally available tree species and can be used as a source of fuel, fencing, shade, to control soil erosion, to maintain soil fertility, as medicine and for construction purposes (Franzel and Wambugu 2007; Chepape *et al.*, 2011; Franzel *et al.*, 2014). Multi-purpose fodder trees are less susceptible to unexpected climatic changes and continue to produce high-quality fodder even during periods of drought when grasses and other annual herbaceous legumes are dry (Hove *et al.*, 2000; Gusha *et al.*, 2015). Most browse plants have a high CP content, ranging from 10 to more than 25% on a DM basis (Moleele 1998; Chepape *et al.*, 2011).

The high DM, organic matter and CP intake from browse leaves can be attributed to the relatively high CP content and low fibre and lignin content of these leaves compared to grasses, especially during dry seasons (Lukhele and van Ryssen, 2003). A positive association between CP content and voluntary feed intake has been reported, while a negative association between fibre and voluntary feed intake persists (Devendra and McLeroy, 1992; Fisher, 2002). Aganga and Monyatsiwa (1999) reported a high DM intake when supplementing goats with browse while Yahaya *et al.* (2000) fed goats only on browse.

For the growth of ruminants, the adequate amount of CP varies between 15-18% in the DM. Quansah and Makkar (2012) considered forages containing CP levels exceeding 16% as very good, between 8% and 16% as good and below 8% as fair.

The two fodder tree species, MO and LL, due to their CP composition of 26.6% and 27.5% respectively represent a good source of protein with a potential of replacing conventional concentrate feed for goats during the dry season. *Moringa Oleifera* leaves showed an improved average daily BW gain when replacing conventional concentrate (Damor *et al.,* 2017), while LL has a beneficial effect on DM intake, weight gain and reproductive performance (Devendra and McLeroy, 1992; Akingbade *et al.*, 2004; Kanani *et al.*, 2006).

Cattle, goats and sheep supplemented on grass-LL mixed pastures and diets (including *Gliricidia sepium*) increased ADG by 44.8, 27.8 and 48.8% respectively, as compared to animals fed on rangeland alone (Muir and Massaete, 1996; Nguluve and Muir, 1999; Pimentel *et al.*, 2011). In goats, improved performance by *Gliricidia sepium* supplementation was also reported by several researchers (Ondiek *et al.*, 2000; Phimphachanhhyongsod and Ledin, 2002; Mpairwe *et al.*, 2003) and in sheep by Fasae *et al.* (2014).

The chemical composition of some dried fodder trees leaves and twigs commonly used as protein sources in tropical and subtropical regions are presented in Table 2.6.

Table 2.6 The chemical composition (% of DM) of some dried fodder trees leaves and twigs commonly used as protein sources in tropical and subtropical agroecosystems

Species	DM	CP	ADF	ADL	Reference
Acacia angustissima[1]	89.9	29.2	45.4	14.3	Larbi *et al.* (1998); Chakeredza *et al.* (2007)
Albizia lebbeck	90.7	19.1	25.4	9.12	Habib *et al.* (2016)
Medicago Sativa	88.8	20.3	26.5	5.49	Kanani *et al.* (2006)
Dolichos lablab	91.0	21.5	24.9	6.49	Kanani *et al.* (2006)
Desmanthus bicornutus	89.9	21.5	12.6	5.48	Kanani *et al.* (2006)
L.leucocephala	90.0	27.5	13.4	5.74	Kanani *et al.* (2006)
Moringa oleifera	90.5	26.6	14.8	8.11	Tona *et al.* (2014); Damor *et al.* (2017)
Gliricidia sepium[2]	No	25.4	31.2	no	Chakeredza *et al.* (2007)
Afzelia africana	91.3	26.7	20.9	-	Olafadehan & Okunade (2018)
Daniellia oliveri	93.9	25.4	20.7	-	Olafadehan & Okunade (2018)
Entada Africana	91.7	21.8	18.2	-	Olafadehan & Okunade (2018)

DM - dry matter; CP - crude protein; ADF - acid detergent fibre; ADL - acid detergent lignin; no: not available

[1]Leaf and twigs; [2]Leaves and stems

According to Olafadehan and Okunade (2018), the use of fodder tree as supplement for goats can replace a concentrate. For, i.e. goats with a basal diet with three different fodder trees resulted in higher ADGs of 86.9 g/head/day, 84.5 g/head/day and 71.4 g/head/day for *Afzelia africana, Daniellia oliveri and Entada Africana* respectively as shown in Table 2.7.

Goats fed with LL had the numerically higher ADG (93.9 g/head/day) compared with 82.3, 76.5 and 60.9 g/head/day for *Medicago sativa*, *Dolichos lablab*, and *Desmanthus bicornutus*, respectively as shown in Table 2.7. The high ADG of goats fed with LL may be due to the high CP concentration (27.5%) (Kanani *et al.*, 2006).

Table 2.7 The effect of fodder tree on daily dry matter intake (g DM/head/day) and performance (g/head/day) of goats

Species	Dry matter intake	Average daily gain (ADG)	Reference
Afzelia africana	347.8	86.9	Olafadehan and Okunade (2018)
Daniellia oliveri	342.4	84.5	
Entada Africana	286.5	71.4	
Medicago sativa	253	82.3	
Dolichos lablab	232	76.5	Kunani *et al.* (2006)
Desmanthus bicornutu	166	60.9	
Leucaena leucocephala	263	93.9	
Moringa oleifera	123.3	61.12	Damor *et al.* (2017)

The most common leaves used as a supplement in Mozambique are LL and *Gliricidia sepium*, in cattle and small ruminant diets (Pimentel *et al.*, 2011), less frequently used are *Artocarpus integrifolia*, *Manihot* and *Sesbania grandiflora* (Patra *et al.*, 2002; Morand-Fehr, 2005). These have all been used in goat protein supplementation as pellets or meals to replace concentrate feeds as excellent protein sources (Srinivasulu *et al.*, 1998; Dutta *et al.*, 2002; Patra *et al.*, 2002). Regarding the use of *Moringa Oleifera* as a goat supplement in Mozambique, there is no data. Therefore, the use of locally available multi-purpose fodder trees as supplements are valuable economic alternatives for smallholder farmers compared to purchased concentrates or agro-industrial by-products (Getu, 2006; Place *et al.*, 2009). Two fodder trees that are common in Mozambique will be discussed in more detail.

Leucaena leucocephala (LL)

Leucaena is a genus of Central American shrubs and trees, belonging to the family *Leguminosae* (*Mimosoideae*) which includes more than 55 species. *Leucaena leucocephala* is a fast-growing leguminous tree and it is an important crop fodder tree encouraged under the social forestry schemes in drought-prone and semi-arid areas. It provides useful timber as well as leaves for fuel, energy and feed purposes (Sethi and Kulkarni, 1995; Mohamed *et al.*, 2015). *Leucaena leucocephala* grows well in well-drained fertile soils from sea level to 1500 meters above sea level (Hughes, 1998).

Aletor and Omodara (1994) evaluated three fodder trees, namely *Leucaena, Gliricidia* and *Cajanus* concerning their chemical composition and concluded that *Leucaena* has a higher nutrient concentration capable of supporting rumen microbial growth and subsequently allowing higher animal performance. The composition of a feedstuff varies according to the fragment, the level of inclusion and category of plant species, the plant parts, the stage of growth and the climate and soils in which the plants grew (Norton, 1994). The composition can also vary based on the state of hydration (fresh or dry) and the drying procedure used (Palmer and Schlink, 1992; Dzowela *et al.*, 1997). Karachi (1998) observed that the nitrogen content in the *Leucaena* species varied between species and between the plant components (e.g. leaves and stems).

The stage of growth of the plant will be discussed in more detail as it is considered the most important factor affecting the chemical composition and digestibility of forage (Marius, 2016). Plant cell wall analysis, based on detergent extraction, is a good indicator for predicting the nutritional value of fibrous feeds because voluntary DM intake and DMD are dependent on cell wall constituents (IAEA, 2006). In general, all forages are highly succulent in early growth, which markedly enhances their palatability. Most plants decline in nutrient composition with advanced maturity (Topps, 1992). Ndlovu *et al.* (1995) reported a decline in CP and *in vitro* dry matter digestibility (IVDMD) while NDF and Acid Detergent Fibre (ADF) increased with leaf maturity of browse. The protein content of forage legumes is generally related to the stage of maturity. Protein content decreases with age while tannin yield increases with age. As the season advances and plants mature, the protein content decreases, hence tannin levels increase (IAEA, 2006). The leaves of LL contain toxins, such as mimosine, but Kumar and Ashwani (1998) showed that after seven to eight weeks, goats can degrade mimosine and are well adapted and continue to increase their growth rate by feeding on LL.

Garcia *et al.* (1996) broadly reviewed the nutritive value of leaves, fresh forage and forage productivity of LL of tree present in Africa, Caribbean and India. For forage, among other parameters, they found average values (g/100 g DM) of 22.03% CP, 35.0% CF, 39.5% NDF, 35.1% ADF, 18.3% ash, 1.80% Ca, 0.26% P, and concluded that the optimum harvesting interval should be about eight weeks or just before the onset of flowering.

The Table 2.8 indicates the nutritive value of fresh or dried leaves of LL (g/100g DM) in terms of CP, ADF, NDF, ash, Ca and P (Norton, 1994; Mohamed *et al*., 2015) In LL, the CP content is well above 7.7g DM (critical value) and higher than the minimum protein requirement of 10-12g per day recommended by NRC (2007) for ruminants.

Table 2.8 Chemical composition of LL (% DM) of forage

Forage Leaves	**Country**	**CP**	**CF**	**ADF**	**NDF**	**ash**	**Ca**	**P**	**Tannin**	**Reference**
Dried L L	Congo	30.56	no	26.4	34.5	10.0	No	no	no	Tshibangu *et al.* (2015)
Fresh L L	Mozambique	24.6	no	no	no	no	No	no	no	Muir &Massaete (1996)
Dried L L	RSA	13.6	no	27.7	51.8	7.2	0.76	0.4	no	Leketa *et al.* (2019)
Dried L L	Tanzania	23.52	no	17.44	26.27	9.70	1.08	0.21	no	Ndemanisho *et al.* (1998)
Fresh L L	Cuba	29.2	19.2	36.10	42	10.5	1.9	0.23	1.01	González-García *et al.* (2009)
Fresh L L	Cuba	22.3	10.5	35.1	39.5	18.3	1.80	0.26	1.05	Garcia *et al.* (1996)
Dried L L	Pakistan	17.4	no	15.2	20.6	12.6	No	no	no	Habib *et al.* (2016)

CP - crude protein; CF - crude fibre; ADF - acid detergent fibre; NDF - Neutral Detergent Fibre; Ca - Calcium; P - Phosphorus; no: not available

Leucaena leucocephala as a meal is highly nutritious with high CP values. Tshibangu *et al* (2015) recorded values greater than 300 g/kg DM. *Leucaena leucocephala* can be used to replace most of the commercial protein sources, such as cottonseed oil cake meal, groundnut cake meal, soya bean meal, oil seed cake meal etc., which are expensive and not locally available in villages in Mozambique (Nyambati, *et al.* 2006; Cowley and Roschinsky, 2019; Leketa *et al.* 2019). The level of NDF in *Leucaena* forage range from 20.6% to 51.8% of DM and is considered highly digestible (Norton, 1994). This is sufficient to support the requirement of small stock ruminants at all production stages (NRC, 2007). The tannin content in a *Leucaena* meal range from 1.01g to 1.05g DM (Garcia *et al.*, 1996; González-García *et al.*, 2009), which is considered as a low to moderate level; this can protect plant protein from rumen degradation and hence decrease ammonia loss (Leketa, 2011).

Goats fed with a basal diet of hay (a graminaceous species mixture of *Setaria palidefusca* and *Imperata cylindrical*) increased the ADG from 17.5 g/head/day to 80g/head/day and protein digested in the small intestine when rumen-fermentable nitrogen is limited (PDIN) from 2.6 g/head/day to 7.0 g/head/day when supplemented with *Leucaena leucocephala* (Tshibangu *et al.*, 2015). Leketa *et al.* (2019) observed that feeding Saanen milk goats with the basal diet in a total mix ration (oilseed cake meal and LL leaf) increased milk yield better than those fed by the control diet (with oilseed cake meal).

Smallholder farmers in Southern Africa can reduce the feeding cost of milk goats by planting Leucaena on their farms and utilising the hay as part of basal diet (Laketa *et al*., 2019). Figure 2.4 shows the different vegetative and reproductive parts of LL tree.

Figure 2.4 Different vegetative and reproductive parts of the LL tree; i) a tree grown in a field, ii) bundle of foliage, iii) flowers; and iv) fruit ([*https://www.alamy.com/stock-photo/leucaena-leucocephala.htm*](https://www.alamy.com/stock-photo/leucaena-leucocephala.htm) Accessed on 11-April -2018).

Supplementation of small East African goats with browse tree leaves improved weight gain with a higher weight gain of goats fed on LL than those supplemented with *Acacia nilotica* and *Acacia polyacantha*, compared to the non-supplemented goats (Rubanza *et al*., 2007).

The ADG of goats was increased from 24.03 g/head/day to 38.06 g/head/day by adding a supplement of LL leaf to goats fed with village feeding (*Panicum maximum*, *Pennisetum purpereum* and *Cynodon dactylon*) as a control (Aregheore *et al*., 2004; Fasae *et al*., 2011).

Moringa oleifera (MO)

Moringa is native to India, a fast-growing tree and widely spread across tropical and subtropical regions (Pereira *et al.,* 2016). *Moringa oliefera* Lam. (moringa) belongs to family *Moringaceae,* and every part of the tree has beneficial properties, making it a multi-purpose tree (Abd El-Hack *et al.,* 2018). The Moringa tree grows mainly in semi-arid tropical and subtropical areas. More generally, Moringa grows in the wild. However, it is cultivated in Central America and the Caribbean, northern countries of South America, Africa, Southeast Asia and various countries of Oceania (Abd El-Hack *et al.*, 2018; Raman *et al.*, 2018). Among the twelve species in the genus Moringa, the most commonly cultivated and widespread is *Moringa oliefera* (Olson, 2002; Nouman *et al.*, 2014; Abd El-Hack *et al.*, 2018). *Moringa oliefera* is native to the sub-Himalayan region of India and Pakistan (Duke, 2001; Shahzad *et al.*, 2013; Nouman *et al.*, 2014).

Moringa oleifera is suitable for various applications and commercial purposes, which can provide benefits to communities (Paliwal *et al.,* 2011). *Moringa oliefera*'s fresh leaves, fruit pods, extracts and meals have high nutritional value including proteins, vitamins, minerals and phytochemicals (CBI, 2016; Abd El-Hack *et al.*, 2018; Raman *et al.*, 2018). The chemical composition of MO of fresh and dried leaves and leaf meal in some regions of sub-Saharan Africa is summarised in Table 2.9.

Table 2.9 Chemical composition of *Moringa oliefera* (%) of fresh and dried leaves and leaf meal

Leaves	Country	DM	CP	CF	Ash	Ca	P	Tannin
MOL	Guinea[1]	88.00	21.30	10.00	9.0	0.51[9]	0.01[9]	no
DMOL	Mozambique[2]	100	28.8	no	10.9	2.21	0.40	no
MOL	Namibia[3]	88.9	21.90	9.73	13.55	1.21	0.27	3.90
MOLM	Nigeria[4, 5]	90.46	18.38	14.04	9.38			no
MOLM	South Africa[6,7]	88.93	23.76	no	no	2.78	0.64	no
MOL	Zimbabwe[8]	87.9	22.50	10.00	11.00	2.03	0.30	no

DM - Dry matter; CP - crude protein; CF - crude fibre; ADF - Acid detergent fibre; NDF - Neutral Detergent Fibre; Ca - Calcium; P - Phosphorus; Tannin - tannic acid; MOL - *M oleifera* leaves; DMOL - Dried *M. oleifera* leaves; MOLM – *M . oleifera* leaf meal and no: not available

Source:[1]Ikyume *et al.* (2018);[2]Mataveia *et al* (2019);[3]Korsor (2018); [4]Yusuf *et al.* (2018); [5]Tona *et al.* (2014); [6]Moyo *et al.* (2011); [7]Qwele *et al.* (2013); [8]Moyo *et al.* (2016); and [9]Asante *et al.* (2014).

The chemical composition of MO fresh and dried leaves and leaf meals from all countries showed nutritive values high enough to maintain nutritional requirements for the physiological functions of goats. The different vegetative and reproductive parts of the MO tree are shown in Figure 2.5.

Figure 2.5 Different vegetative and reproductive parts of MO tree; i) a tree grown in the field, ii) bundle of foliage, iii) flowers; and iv) fruit (pod). Source: Saini *et al.* (2016).

The MO tree is abundant even in the dry season. Several studies (Tona *et al*., 2014; Damor *et al*., 2017; Choudhary *et al*., 2018; Meel *et al*., 2018) showed that *Moringa oleife*ra can be used to replace the conventional concentrate diet of ruminants and improve livestock performance, i.e. body weight and average daily body weight gain as well as feed intake. Additionally, the use of MO leaves in lactating goat diets can improve the feed intake and milk yield (Kholif *et al*., 2015; Kholif *et al*., 2017).

The daily weight gain of Bengal goats was progressively increased when the inclusion of MO dried leaves was increased in the diet of does from 23.21 g/head/day to 25.71 and 34.64 g/head/day with concentrate mixture at 0% MO, 30% MO and 50% MO, respectively (Choudhary *et al*., 2018). Damor *et al.* (2017) have also recorded a similar trend, where the ADG of Mehsana goat kids that were fed by basal diet increased from 50.36 g/head/day to 54.60 and 61.12 g/head/day with concentrate (0% MO), concentrate mixture (50% MO) and solely MO leaves (100% MO), respectively. Likewise, the concentrate was gradually replaced by MO dry leaves at four different levels, and was observed that the ADG of Sirohi goat kids increased from 29.72 g/head/day to 38.43, 50.22 and 57.59 g/head/day, respectively when the supplementation was increased from 533.51 g/head/day, 545.72, 575.25 to 586.78 g/head/day, respectively (Meel *et al*., 2018).

According to Tona *et al*. (2014), the inclusions of MO leaf meals in four different levels in a goat's basal diet (*Panicum maximum* grass and concentrate) were responsible for increases in the CP contents of the diets up to, 27.03%, 37.20%, 39.97% and 41.00%. The daily weight gain of goats fed with a basal diet (*Panicum maximum* grass) increased from 21.15 g/day to 22.79 g/day and DMI from 354.92 to 392.46 g/day when the level of inclusions of MO leaf meals increased from 0% to 15%, respectively (Tona *et al.*, (2014). Likewise, does fed with MO (50%) had higher milk yield (0.33 kg/day) than those fed with 30% of MO (0.29 kg/day) in the concentrate mixture diet and those fed only the concentrate mixture diet without MO had a 0.27 kg/day milk yield (Choudhary *et al*., 2018).

The nutritional properties of LL and MO are presented in Table 2.10, where the ME varies from 11.00 to 11.05 MJ/kg of DM. The lowest ME was in MO while the highest was in LL. The CP of MO was higher (30.99 g/100 g of DM) than the 23.7g/100g of DM in LL. However, the values agree with those reported by Fadiyimu *et al.* (2011), who described the high protein content in the fodder trees ranging from 12 to 31.2%. Table 2.10 presents the nutritional properties of two Mozambican trees with great potential as a supplement (LL and MO).

Table 2.10 The nutritional properties of LL and MO

Feeder trees	**Nutrient contents (on Dry Matter basis)**			
	ME (MJ/kg DM)	**CP (%)**	**Ca (%)**	**P (%)**
Leucaena leucocepha[1]	11.05	23.70	3.26	0.15
Moringa oleifera[2]	11.00	30.99	1.21	0.27

Source: [1] Ndemanisho *et al.* (1998); [2]Korsor (2018)

The effects of supplementating of MO and LL fodder tree on goat growth are shown in Table 2.11. The ADG g/day was high, with 66.70 g/head/day as reported by Yusuf *et al.* (2018) when the inclusion of MO leaf meal was at 100%; while the lowest was 16.07 g/head/day reported by Tona *et al.* (2014) when the inclusion of MO leaf meal was at 5%. Moreover, in both species of fodder tree, there is a limit of inclusion of supplementation. MO leaf meals showed the limit of inclusion by 15% with the high 22.79 g/head/day ADG value, as reported by Tona *et al.* (2014). Alternatively, whilst the LL was observed at a limit of inclusion of 30%, it had a high

ADG 38.00 g/head/day, as reported by Yami *et al.* (2000). After those levels of inclusion, the fodder tree as a supplement had no significant effect observed in ADG/goat.

Table 2.11 Effect of supplementation of MO and LL fodder tree on the growing of goats

Fodder trees	**Breed**	**% Inclusion level**	**Avarage daily gain (g/head/day)**	
	Males	0	21.15[1]	55.70[3]
	West African Dwarf goats	5	16.07[1]	-
M. oleifera		10	16.72[1]	-
		15	22.79[1]	-
		50	-	63.30[3]
		100	-	66.70[3]
	Females	0	48.00[2]	-
	Angora and Spanish goats	15	28.00[2]	-
L. leucocephala		30	38.00[2]	-
		45	34.00[2]	-
		60	26.00[2]	-

Source:

[1]Tona *et al.* (2014), basal diet: concentrate mixture (dried cassava peels, Palm kernel cake and Bone meal);
[2]Yami *et al.* (2000), basal diet: concentrate mixture (cottonseed hulls, ground corn, formaldehyde-treated casein and molasses);
[3]Yusuf *et al.* (2018), basal diet: concentrate mixture (palm kernel cake, wheat offal, rice bran and oat meal)

Anti-nutritional factors in fodder trees

Different tree fodders (shrubs, herbs, trees) may contain vaarious anti-nutritional components in both the fresh and dry matter basis. These act as food reserves or as a defense against insect and fungal attacks and also serve an adaptive mechanism to their environment (Kumar, 1992; Tedla, 2014; Ramteke *et al.*, 2019).

The nutritional contribution of the leaves and trees as an animal feed can be limited by the presence of toxic substances. Anti-nutritive substances are toxic components such as nitrate, mimosine, tanin, coumarins, oxalate, sinogen, saponins and can be harmful to ruminants. The anti-nutritional factors have a negative effect when consumed by animals in large quantities, such as decreased animal productivity. They could also cause toxicity during periods of nutritional scarcity or confinement resulting in mortalities. Feeding animals with tree fodder above the recommended amounts is thus not advisable because the toxic/anti-nutritive components can cause toxicity with lethal consequences for the animals (Forbes, 2007; Tedla, 2014; Ramteke *et al.*, 2019).

One of the most abundant polyphenolic compounds in plants is represented by tannins. Among the anti-nutritional factors, tannins are the most widely occurring compound in fodder trees. By slowly adapting the ruminal microbes to the toxic effects of condensed tannins (CT) and by releasing CT-binding salivary proteins, the ruminants can tolerate CT. The protein-binding ability of condensed tannins has some benefits to the ruminant due to complexes formed with essential amino acids, preventing their degradation in the rumen, but releasing them in the lower gut for absorption by the animal. In small ruminants there are potential benefits of using hydrolysable (HT) and condensed tannins (CT) for anthelmintic purposes due to their ability to inhibit egg hatching and larval motility of gastrointestinal nematode parasites (Aemiro *et al*., 2004; Assefa, 2007; Tedla, 2014; Ramteke *et al.*, 2019). In *Leucaena* meal, the tannin content is considered as a low to moderate level, which may range from 0.51% – 1.6% (Leketa *et al.*, 2011).

Like all species belonging to the sub family Mimosolidae, *Leucaena* contains a toxic substance called mimosine. Mimosine is a naturally occurring non-protein, free amino acid. Although mimosine is considered as a toxic agent it does not cause many problems in the rumen, because most problems (which are rarely acute) are caused by mimosine derivatives. The toxicity of mimosine in animals is associated with the interference of cellular mitosis and with alopecia. Mimosine comprises 3.5% of the protein of Leucaena fodder. When using Leucaena, the level of incorporation should not exceed 10% of total DM intake, otherwise it can cause loss in weight, loss of appetite, stunted growth, goiter and aleopecia (Garcia *et al*., 1996; Leketa *et al.*, 2011).

Conclusions

Goats have been associated with humanity since their domestication at least 10 000 years ago, and approximately 96% of these animals are found in developing countries and are kept for small-scale production purposes in rural areas where tethering are the common feeding management practices with limited supplementation during the dry season. Indigenous goats are essential in the livelihoods of limited-resource populations in developing countries. Due to their ability to adapt to harsh environmental conditions and different foods, goats can maintain production and reproduction performance effectively. Goats depend primarily on natural veld for physiological functions, but the shortage of forage in dry seasons, due to the uncontrolled fire and low quality of available forage has been recognised as one of the foremost causes of nutritional stress which limits animal production in (sub)tropical regions. Supplementing goats with highly nutritive alternative fodder tree sources has a positive effect on animal performance and contributes to increased goat productivity. The use of fodder trees as a supplement represents a good and inexpensive alternative to commercial supplements that can be used by smallholder farmers for feeding goats during periods of feed scarcity. *Moringa. oleifera* and *L. leucocephala* can be used to replace the convetional supplements to feed goats during the dry season.

CHAPTER 3

SMALLHOLDER GOAT PRODUCTION IN THE NAMAACHA AND MOAMBA DISTRICTS OF SOUTHERN MOZAMBIQUE

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Smallholder goat production in the Namaacha and Moamba districts of southern Mozambique

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Abstract

Goat rearing is one of the most common livestock farming activities in Mozambique and has the potential to play a powerful role in improving the livelihoods of resource-poor farmers. This study was conducted to investigate the status of goat husbandry practices in rural areas of southern Mozambique. Data were collected from a total of 45 smallholder goat keepers in three different villages through questionnaires complemented by interviews. Most households were dependent on crop production and livestock as their main source of income. Goats were reared under extensive systems where free grazing and tethering were the common feeding management practices with limited supplementation during the dry season. The flock sizes per household were predominantly small (13 ±2.4) with uncontrolled breeding of goats.

The goats were reared mainly as a source of meat for home consumption and a means of reserve cash income. All household members were involved in goat production but women and children had a minor role in terms of decision-making. The main constrains limiting goat production were diseases, lack of veterinary services, limited size of grazing land and scarcity of feed resources. Intervention programs focused on improving the husbandry practices and veterinary assistance should be initiated to improve goat production and thereby improve the income and livelihood of the resource-poor farmers in Mozambique. This paper presents a summary of the results of a baseline study in the Namaacha and Moamba districts of Mozambique.

Keywords: communal, extensive, goat, husbandry, small-scale

Introduction

Goats are kept in a wide range of agro-ecological zones and management systems, and are mainly owned by smallholder farmers in developing countries (Casey & Webb, 2010), where they contribute to improved livelihoods for many resource-poor communities (De Vries, 2008; FAO, 2012; Hossain *et al.,* 2015; Ouchene-Khelifi *et al.,* 2015). Their role and relative importance varies noticeably across regions and cultural groups. In addition to providing meat and milk for household consumption, goats are one of the easiest and most readily accessible sources of income available to meet the immediate social and financial needs of rural farmers (Boogaard *et al*., 2012; Boogaard & Moyo, 2015). Furthermore, they are used for cultural purposes such as traditional ceremonies and birthday festivities (Kosgey *et al.,* 2008; Rumosa Gwaze *et al.,* 2009; Oluwatayo & Oluwatayo 2012; Boogaard *et al*., 2012). Goats are mostly owned by smallholder farmers and have comparative advantages over other livestock species in the traditional farming systems due to their rapid turnover, adaptability to harsh environmental conditions and the efficient use of available feeding resources (Braker *et al.,* 2002). Goat production worldwide grew steadily in the last decade, particularly in the developing world, with Africa contributing approximately 36.2% to the global goat population (FAOSTAT, 2014).

In Mozambique, goat population is estimated at about 5 million head, of which almost 95% are kept by rural smallholder farmers and less than 1% is farmed commercially (INE, 2014). Mozambique has two indigenous goat breeds, namely the Landim breed which is spread across the country, and the Pafuri breed, which is mostly located in the semi-arid area of Pafuri in South-West Mozambique (Garrine *et al.,* 2010). Goats are commonly raised under a mixed crop-livestock management system, where they subsist on grazing on natural veld and shrubs or marginal lands, and sometimes on crop residues (Devendra & McLeroy 1982).

However, the prevalence of a long dry season and droughts in the country poses major challenges to most goat keepers as it leads to shortages of forage and water. In addition, the reduction of grazing land for ruminants associated with increasing human population size and its subsequent degradation, uncontrolled fires and an absence of pasture management exacerbate the shortage of fodder for goats (Timberlake & Jordão, 1985). This problem leads to underfeeding of goats and consequently, loss of body condition, reduced productivity, increased susceptibility to diseases, and high mortality rates (Kanani *et al.,* 2006).

In Mozambique past efforts aimed at improving goat production are limited. The development of goat improvement programs would be more effective if information regarding the prevailing goat farming systems in the country were available. In order to design appropriate strategies aimed to improve goat production and to explore the potential contribution of goats to food security in resource-poor areas, there is a need to evaluate the existing goat production system and its role in these rural communities. This study was therefore conducted with the objective of generating baseline information with regard to the current goat husbandry practices in the rural areas of southern Mozambique (Maputo province). It aims to characterize the existing rural goat production system with regards to socio-economic factors, general management and limits encountered.

Materials and methods

Study setting

The study was conducted in two districts (Namaacha and Moamba) of the Maputo province in southern Mozambique.

These districts were selected because of their importance in goat production and their proximity to the Extension Centre of the Eduardo Mondlane University. The Namaacha district covers an area of 2,196 km2 and is characterised by a humid tropical climate with an average annual rainfall of 751 mm. However, the district has experienced a substantial decrease in rainfall over the last years, having received an annual rainfall of 260 mm in 2015 and 471mm in 2016.

Most parts of the district are classified as semi-arid, with visible land degradation due to poor management caused by overgrazing (MAE, 2005). The Moamba district, covering an area of 4,598 km^2, is characterised by a subtropical dry climate, with an annual rainfall ranging between 580 and 590 mm. In both districts, the average annual temperature varies between 23 °C and 24 °C, with maximum highs of 36 °C. The rainy season is from October to April and the dry season is from May to September. According to Timberlake & Jordão (1985) and Morgado (2007), the vegetation consists mainly of grasses (*Andropogon gayanus*, *Cynodon dactylon*, *Eragrostis superba*, *Panicum maximum*, *Setaria holstii*, *Themeda triandra*, *Urochloa mosambicensis*), and shrubs and trees (*Acacia nigrescens*, *Acacia nilotica*, *Dichrostachys cinerea*, *Sclerocarya birrea*).

Sampling and data collection

Prior to the study, goat keepers from both districts were approached to evaluate their willingness to participate in the study. Three villages (Michangulene and Mahelane from

Namaacha district, and Moamba-sede from Moamba) were chosen and fifteen goat keepers were randomly selected from each village to participate in the study, resulting in a total of 45 goat keepers. Information regarding household demographics and goat management practices (e.g. feeding, health, reproduction and constraints) was collected through questionnaires. Participants ranked certain parameters such as major sources of income and reason for keeping goat on a scale of 1 to 3, with 1 being the most important and 3 the least important. The questionnaires were complemented by directed observations to collect additional qualitative data. The interviews were performed by the principal investigator and a trained enumerator. In order to ensure that all questions were clear to the interviewees, the questionnaire was pre-tested before the survey and was translated into the local language where necessary. Before the commencement of the study, consent was obtained from the villages' leaders and from each individual respondent.

Data on livestock number was converted to tropical livestock unit (TLU) according to Mburu *et al*. (2011). TLU is a common unit to describe livestock numbers across species to produce a single figure indicating the total 'amount' of livestock owned. The number of units obtained for a given livestock species is multiplied by the appropriate conversion factor for TLU, which for goats corresponded to 0.10 TLU (Tumusiime *et al*., 2006).

Data analysis

Data were captured in EpiData Entry Client version 4.0 (Lauritsen & Bruus, 2005) and exported to SPSS version 20.0 (IBM Corp, 2011) for analysis. Data were analysed using descriptive statistics, wherein means and standard deviations were obtained for quantitative data and frequency and percentages were obtained for categorical data. The source of income, purpose of rearing goats, reasons for choice of buck and marketing/culling of goats were subjected to a rank analysis according to the perceived grade provided by the goat keepers. Indices were calculated using the following formula: Index =sum of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] given for an individual use divided by the sum of [3 for rank 1 + 2 for rank 2 + 1 for rank 3] summed over all uses.

Results

Socio economic characteristics of households

Socio economic characteristics of the households included in the study are presented in Table 3.1. The majority of the respondents (95.6%) surveyed in all three villages owned their land. Of the households surveyed, most (71.1%) were headed by males. However, there was a substantial number of female-headed households in Michangulene (33.3%) and Mahelane (46.7%). Most household heads (73.3%) were over 45 years old, and had attained some level of formal education (64.4%). Results on additional household characteristics (marital status and household size) are also presented in Table 3.1.

Table 3.1 Socio-economic characteristics of goat keeping households in the three study villages

Parameters	*Villages*			Total
	Michangulene	*Mahelane*	*Moamba*	
Land holding (%)				
Own	86.7	100	100	95.6
Lease	6.7	0.0	0.0	2.2
Other	6.7	0.0	0.0	2.2
Sex of household head (%)				
Male	66.7	53.3	93.3	71.1
Female	33.3	46.7	6.7	28.9
Age group of household head (%)				
⩽ 30	0.0	13.3	6.7	6.7
31 – 45	26.7	0.0	33.3	20.0
46 – 60	33.3	73.3	20.0	42.2
> 60	40.0	13.3	40.0	31.1
Marital status of household head (%)				
Married	73.3	80.0	66.7	73.3
Single	20.0	13.3	13.3	15.6
Widower / Widow	6.7	6.7	20.0	11.1
Level of education of the household head (%)				
Primary	60.0	40.0	33.3	44.4
Secondary	6.7	6.7	20.0	11.1
Tertiary	0.0	13.3	13.3	8.9
None	33.3	40.0	33.3	35.6
Household size (mean±sd)				
Male	1.5±1.1	1.6±0.8	2.2±1.6	1.8±1.2
Female	1.8±0.9	1.9±0.9	1.9±1.8	1.8±1.3
Children (< 15 years)	2.1±1.5	4.1±3.0	4.7±12.9	3.6±7.7
Total	5.3±2.6	7.6±3.6	8.8±13.5	7.2±8.2

Generally, the household members shared roles and responsibilities regarding goat husbandry activities. Overall, Table 3.2 shows that in Moamba and Mahelane villages mainly men are responsible for goat husbandry, while in Michangulene village, activities are more evenly spread over men and women. However, in latter village women are largely responsible for some activities, such as breading, purchasing and selling, although this percentage is clear lower in the other two villages. Table 3.2 also shows that children are to a high extent responsible for the herding/feeding of the goats in Michangulene and Mahelane villages.

Table 3.2 Extent of household members' participation (%) in various goat husbandry activities in the three study villages

Activity	*Michangulene*			*Mahelane*			*Moamba*		
	Men	*Women*	*Children*	*Men*	*Women*	*Children*	*Men*	*Women*	*Children*
Herding/Feeding	14.3	42.9	42.9	6.2	18.8	75.0	83.3	16.7	0.0
Breeding decisions	35.7	64.3	0.0	66.7	33.3	0.0	93.3	6.7	0.0
Slaughtering	57.1	42.9	0.0	71.4	28.6	0.0	93.3	6.7	0.0
Selling	47.1	52.9	0.0	70.0	30.0	0.0	93.3	6.7	0.0
Purchasing	38.5	61.5	0.0	71.4	28.6	0.0	92.9	7.1	0.0
Animal health care	54.5	45.5	0.0	66.7	33.3	0.0	90.0	10.0	0.0

The majority of surveyed households in the study village were dependent on mixed crop and livestock production as their main source of income. Crop production such as maize, beans and cassava was ranked as the primary source of income in Michangulene and Mahelane, while in Moamba, livestock was ranked highest (Table 3.3). In addition to crops, other sources of income regarded as important in Mahelane and Michangulene were earning a salary as farm workers and livestock, while informal business related activities also played an important role as source of income in Moamba village.

Table 3.3 Ranking of source of income in households in the three study villages

Source of income	**Rank (Index)**		
	Michangulene	*Mahelane*	*Moamba*
Salary	2nd (0.12)	2nd (0.33)	4th (0.05)
Crops	1st (0.56)	1st (0.40)	2nd (0.38)
Livestock	3rd (0.32)	3rd (0.24)	1st (0.44)
Business	4th (0.00)	4th (0.03)	3rd (0.14)

The average livestock holding per household was higher in Moamba village (14.0±3.55 TLU) than the other two villages (Table 3.4). Among livestock type, average cattle holding was also higher in Moamba (11.1±3.03 TLU). In terms of number of heads, goats were the major livestock species kept by the households in Michangulene followed by chickens and pigs, while in Mahelane and Moamba chickens were kept in higher numbers, followed by goats and cattle. Irrespective of village, goats were kept in larger numbers (13.04±2.41 head) when compared to cattle (6.76±1.88 head) and pigs (1.20±0.44 head). With regard to the number of goats kept by village, Moamba had larger flock sizes (23.0±6.39 head) compared to Michangulene (8.0±1.2 head) and Mahelane (8.13±1.48 head).

Table 3.4 Herd size (Mean ± SE) per household in the three study villages

Livestock type	Number of heads			TLU*		
	Michangulene	Mahelane	Moamba	Michangulene	Mahelane	Moamba
Cattle	0.3±0.21	4.2±2.33	15.8±4.32	0.2±0.14	2.9±1.64	11.1±3.03
Goats	8.0±1.20	8.1±1.48	23.0±6.39	0.8±0.12	0.8±0.15	2.3±0.64
Sheep	0.0±0.00	0.3±0.26	3.7±2.80	0.0±0.00	0.0±0.03	0.4±0.28
Chicken	5.3±0.82	12.2±3.17	24.9±7.40	0.1±0.01	0.1±0.03	0.2±0.07
Pigs	1.5±0.82	1.9±1.01	0.2±0.20	0.3±0.16	0.4±0.20	0.0±0.04
Other♣	1.67±0.62	7.93±6.54	1.20±0.52	-	-	-
Total herd size				**1.3±0.25**	**4.3±1.93**	**14.0±3.55**

*TLU - Tropical Livestock Unit; TLU is a common unit to describe livestock numbers across species to produce a single figure indicating the total 'amount' of livestock owned (Mburu *et al.*, 2011). ♣Includes ducks, rabbits and donkeys

Reason for keeping goats

The reason for rearing goats was evaluated based on the rank attributed to each specific purpose by the goat keepers. Generally, most goat keepers primarily used goats as a source of meat for home consumption and cash income from sales (Table 3.5). In Mahelane and Michangulene villages, the use of goats for social ceremonies and for investments/insurance, respectively, were indicated as other important reasons for rearing goats.

Table 3.5 Purpose of keeping goats as ranked by goat keepers in the three study villages

Purpose	Rank (index)		
	Michangulene	*Mahelane*	*Moamba*
Meat	2^{nd} (0.20)	1^{st} (0.29)	1^{st} (0.26)
Skin	6^{th} (0.01)	7^{th} (0.00)	6^{th} (0.00)
Cash from Sales	1^{st} (0.21)	3^{rd} (0.13)	1^{st} (0.26)
Ceremonies	5^{th} (0.08)	2^{nd} (0.21)	2^{nd} (0.17)
Breeding	3^{rd} (0.17)	4^{th} (0.11)	3^{rd} (0.16)
Insurance/emergency	2^{nd} (0.20)	6^{th} (0.06)	5^{th} (0.04)
Cultural rites	6^{th} (0.01)	5^{th} (0.10)	4^{th} (0.07)
Investment	4^{th} (0.12)	5^{th} (0.10)	5^{th} (0.04)

Important traits for goat keepers

Goat keepers indicated their preferences in terms of phenotypic traits and the ranking thereof is presented in Table 3.6. In general, all traits were considered important, however, body size, growth rate, disease and drought tolerance were considered the most important traits for male goats, while prolificacy and fertility traits were ranked very high for female goats. Irrespective of the sex of the goat, the traits that were considered as being the foremost important were body size in Michangule, while growth rate and quality of meat were ranked at the top in Mahelane, and grow rate and body size in Moamba.

Table 3.6 Preferred traits as ranked by goat keepers in the three study villages

	Rank (index)					
Reason	***Michangulene***		***Mahelane***		***Moamba***	
	Bucks	***Does***	***Bucks***	***Does***	***Bucks***	***Does***
Growth rate	2nd (0.10)	2nd (0.10)	1st (0.10)	1st (0.10)	1st (0.10)	1st (0.10)
Body size	1st (0.11)	1st (0.11)	2nd (0.09)	2nd (0.09)	1st (0.10)	1st (0.10)
Meat quality	4th (0.07)	3rd (0.09)	1st (0.10)	1st (0.10)	1st (0.10)	2nd (0.09)
Prolificacy	3rd (0.09)	1st (0.11)	2nd (0.09)	1st (0.10)	2nd (0.09)	2nd (0.09)
Disease tolerance	1st (0.11)	2nd (0.10)	3rd (0.08)	3rd (0.08)	2nd (0.09)	2nd (0.09)
Drought tolerance	2nd (0.10)	3rd (0.09)	3rd (0.08)	3rd (0.08)	2nd (0.09)	2nd (0.09)
Heat tolerance	2nd (0.10)	4th (0.08)	2nd (0.09)	2nd (0.09)	2nd (0.09)	2nd (0.09)
Temperament	2nd (0.10)	2nd (0.10)	1st (0.10)	1st (0.10)	2nd (0.09)	2nd (0.09)
Body shape	2nd (0.10)	2nd (0.10)	2nd (0.09)	3rd (0.08)	4th (0.07)	3rd (0.08)
Colour	5th (0.03)	5th (0.02)	2nd (0.09)	3rd (0.08)	3rd (0.08)	3rd (0.08)
Fertility	1st (0.11)	2nd (0.10)	1st (0.10)	1st (0.10)	1st (0.10)	2nd (0.09)

Production system

Goats were raised under extensive conditions where they were allowed to graze either freely on communal grazing areas, herded or tethered. In Michangulene and Mahelane villages, children were at large responsible for herding the goats to grazing areas during the day, while in Moamba village goats mostly grazed unsupervised during the day and confined at night. Tethering was also a common practice in the Michangulene and Mahelane villages (50 – 93.3%). Although supplementary feeding was not common, some goat keepers (7.1– 53.3%) in the Michangulene and Mahelane villages provided crop residues and leaves from fodder trees, such as *Leucaena leucocephala* and *Moringa oleifera* mainly during the dry season.

The major sources of water for goats were boreholes in the Michangulene and Mahelane villages, and a river in the Moamba village. These water sources provided water for the goats throughout the year and were usually located near to the households in the case of boreholes, while the river was distant from the households.

Most goat keepers (60 – 98%) housed their goats in own kraals throughout the year. The kraals were used to keep the goats safe during the nights, while they were either left to browse or tethered during the day. The kraals were mostly traditional, made of untreated wood and with earth floors. Approximately half of the kraals in the Namaacha villages (Michangulene and Mahelane) had an iron sheet roof to protect the animals from the rain, while in Moamba the kraals were mostly open.

Goat flocks consisted of local breeds where kids and weaners formed the major part of the flock structure. The main source of goats for the majority of goat keepers (46.7 – 93.3%) was purchasing from other goat keepers across the study villages. Within their own flocks, most goat keepers (53.3 – 63.6%) used their own breeding bucks for natural breeding. However, in Mahelane village, goat keepers were largely dependent on the use of communal breeding bucks (60%).

Although breeding was uncontrolled, the choice of bucks for mating was based mainly on their body size (39.0 –100%), while other selection criteria such as body shape and performance (11.0– 33.0%) were also important. Buck performance and body shape were ranked second in Mahelane (11.0 and 29%, respectively) and Moamba (33.0 and 19.0%, respectively). Other traits, such as colour and availability, were generally perceived as being less important.

Bucks were used for breeding from as young as 6 months (46.7 – 86.7%) and their breeding life lasted typically between 2 to 4 years. The majority of goat keepers (46.7 – 64.3%) reported ages at first kidding to be between 12 and 18 months. However, a substantial portion of respondents (28.6 – 50.0%) also reported early kidding ages of between 6 and 12 months. The kidding interval was commonly between 6 and 8 months, but sometimes it lasted as long as 12 months. Natural weaning was the sole practice of weaning and many goat keepers did not allow kids to wean before 4 months of age.

In general, culling was a common practice among goat keepers (20 – 73.3%) in the villages. Old age and temperament were the main reasons for removing male goats from the flocks, while poor fertility and old age were the main reason for culling of females. All culled animals were marketed either to consumers or to other goat keepers. Apart from culling, selling of goats was also common practice (50.0 – 68.8%). Male goats constituted the major proportion of goats sold (20 – 73.3%) as compared to females (0 – 13.3%). Goats were sold mainly to cover household needs, such as food, school fees, medicines and traditional ceremonies.

Constraints to goat production

The households generally considered health issues as the most important constraint for goat production, where diarrhoea was stated as the main concern, followed by respiratory problems and ectoparasites. Theft of goats, limited grazing areas particularly in Michangulene and Mahelane, as well as a shortage in quantity and good quality pastures in the dry season, and insufficient veterinary/extension assistance were the other constraints reported (Figure 3.1).

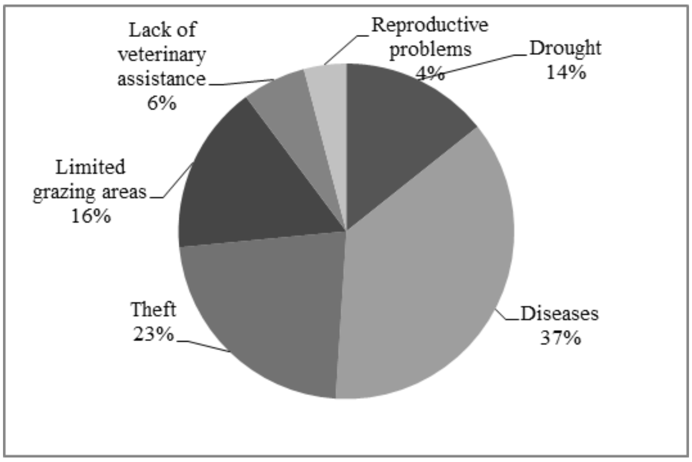

Figure 3.1 Constraints for goat production in the three study villages

Discussion

Communal, indigenous goats are mostly kept by rural communities and play a crucial role in food security and improving livelihoods (Hossain *et al*., 2015; Ouchene-Khelifi *et al*., 2015). Most research on goats has been performed in controlled research conditions and is usually not applicable to the rural conditions in which animals are kept. Rumosa Gazwe *et al*. (2009) stressed that surveys to collect baseline data using questionnaires, discussions and direct observations from goat keepers, are essential for goat development in Southern Africa.

Demographic characteristics of this study indicated that while males are still dominating as heads of households, women do have reasonably good participation in the goat production systems. However, goat husbandry is largely a male activity in Moamba village, probably due to traditional habits prevailing in that area whereby men own and are responsible for livestock, while women are relegated to crop production and domestic duties. In contrast, in Michangulene and Mahelane villages the involvement of women in goat activities is more pronounced, likely because men are engaged in other activities, either as farm workers, or other occupations locally or at nearby industrial plants in Maputo province. Furthermore, the university centre located at Michangulene village has been developing gender-based livestock programs which might have contributed to the involvement of more women in goat production. According to Guèye (2009), development programmes aimed to enhance the role of rural female farmers in agro-production systems have the potential to empower women over time. On the other hand, the absence of children in goat activities observed in Moamba village might reflect the husbandry system used in that area, whereby cattle and goats are not herded to the grazing and watering points, whereas the increasing human population in Michangulene and Mahelane may have contributed to an increased level of goat's thefts, resulting in the need of a supervised grazing or tethering.

Although most households owned some land in the study areas, it has mainly been used for crop farming. While in Moamba village, grazing land is not yet a problem, the increasing need of land for habitation in Michangulene and Mahelane villages, has been reducing the areas formerly used for grazing. Previous studies have pointed that the land available for agriculture activities has been negatively affected by the increasing human population (Berihu *et al.*, 2015; Kalema *et al.*, 2015). Goats are only allowed to graze in fallow lands or shared grazing areas within the communities. These findings are in line with those reported in other studies targeting small ruminants (Simela & Merkel, 2008; Kosgey *et al.*, 2008; Oluwatayo & Oluwatayo 2012). Limited grazing land pose an important challenge to smallholder goat farming since it negatively affects the quantity as well as the quality of available fodder and consequently the reproduction efficiency and health of goats, and therefore the role these animals play in the livelihoods of the rural poor.

The larger TLU and goat flock size observed in Moamba village may probably reflect the availability of grazing areas and other conditions when compared to Michangulene and Mahelane villages. However, overall average flock size (13.04±2.41 head) found in the present study corresponds to the large range previously reported for rural goat herd sizes. Average goat flock sizes in Southern Africa varies from 9.7 in Mozambique (van Niekerk & Pimentel, 2004) and 12.0 in Zimbabwe (Sibanda & Assan, 2014) to 16.0 and 25.3 in South Africa as reported by Mahanjana & Cronjé (2000) and Mdladla *et al.* (2017), respectively. Flock sizes in communal areas are generally limited by little available grazing land available, low reproduction efficiency and high prevalence of parasites and diseases (Rumosa Gwaze *et al*., 2009).

Rural smallholder farmers in Mozambique depend on mixed crop-livestock farming for their subsistence. Goats are raised primarily as a source of meat for home consumption and to use as cash reserve, and the finding of this study is in agreement with observations from previous studies conducted in other African countries (Collins-Lusweti, 2000; Kosgey *et al*., 2008; Rumosa Gwaze *et al*., 2009; Semakula *et al*., 2010; Oluwatayo & Oluwatayo 2012; Hassan & Tesfaye, 2014).

Variation in the importance of livestock as a source of income is normal, as it depends on the production environment as well as the proximity to markets (Monau *et al*., 2017). In villages closer to urban areas, goat keepers are more prone to have other means of income such as informal employment. The use of goats in social ceremonies was ranked second in some areas (Moamba and Mahelane), which emphasizes the socio-cultural importance of goats in rural areas of Mozambique. The importance of selection criteria is vital in goat breeding and has been reported to vary according to production systems in the tropics (Kosgey & Okeyo, 2007). In this study, body size and growth rate as well as disease and drought tolerance were considered the most important traits for male goats. In addition to these traits, prolificacy was considered as a major trait in female goats. Body size and growth rate are valued since they are linked to improved weight gains and hence to increased income and meat. Similarly, disease and drought tolerance were emphasised by farmers due to their influence on flock production. This corresponds to the traits used for selection in West African goats (Dossa *et al*., 2015), which also ranged from health status and body conformation to tolerance and drought and disease resistance. In Botswana, Monau *et al*. (2017) also reported that body conformation and body size were the two most important characteristics for selection of Tswana goats. Lack of tolerance to droughts and diseases predisposes animals to loss of body condition and therefore results in reduced productivity (Kanani *et al.* 2006). When selecting male breeding animals, farmers put most emphasis on body size, being an indicator of meat production. These findings are consistent with previous reports from Ethiopia (Tadesse *et al.,* 2014), Uganda (Byaruhanga *et al*., 2015) and West Africa (Dossa *et al*., 2015).

This study shows that farmers value animals that have shown an ability to survive and thrive under stressful environmental conditions. Prolificacy and fertility are also valued traits for female goats since they influence the growth and productivity of the flock. It is clear from this study that goat farmers rely on multiple selection criteria to ensure adaptability to the local environment and increase goat production.

This study showed that most of the animals grazed on poor-quality natural veld in communal land. This practice is common in extensive smallholder systems and is used in many resource-poor areas of the developing countries where cattle, goats and sheep depend on natural vegetation as their primary source of feed (Kusiluka & Kambarage, 1996; Salem & Smith, 2008; Kumar *et al*., 2010; Byaruhanga *et al.,* 2015). Tethering was a common management practice and was used throughout the year, particularly in Michangulene and Mahelane. This practice was used to prevent stock theft and destruction of crops during the cropping season, while it also limits the animals to a specific area with sufficient vegetation. While tethering is a common practice in goat keeping in many parts of Africa (Banda *et al.,* 1993; Lovelace *et al.,* 1993; Webb & Mamabolo, 2004; Boogaard *et al*., 2012), it can have an adverse effect on goat production.

It generally leads to restricted feeding and therefore results in inadequate nutrition (Salem & Smith, 2008; Byaruhanga *et al.*, 2015), particularly if supplementary feeding is not provided or the alternative available is of low quality. Supplements were provided for goats mainly during the dry season when feeding resources were scarce. Supplementation consisted mainly of crop residues and leaves from trees species such as *Leucaena leucocephala* and *Moringa oleifera*. This practice was largely observed in villages where tethering was common, suggesting that the practice of tethering forced farmers to provide supplementary fodder to meet feeding and nutritional needs of the animals. However, supplementation was not practiced at all in the Moamba village, where farmers indicated that they were not aware of the nutritional qualities of the fodder trees such as *Leucaena leucocephala* and *Moringa oleifera*. This indicates the importance of extension and knowledge transfer regarding such alternative fodder resources.

The fodder trees can easily be grown in this study area and will relieve grazing pressure during the prolonged droughts. The use of supplementary feed sources, such as maize grain and flours has been reported as a common practice in other studies conducted in resource poor areas of Asia and Africa (Cullins-Lusweti, 2000; Kumar *et al.,* 2010; Boogaard *et al*., 2012; Tadesse *et al.,* 2014; Byaruhanga *et al.,* 2015) as a way of meeting maintenance requirements and sustaining body condition and flock productivity during the dry seasons.

Goats usually graze communal fields that are unfenced, and this makes them vulnerable to predators and thieves. Protection from stock theft during the night is the main reason for providing housing. The housing was basic and did not allow systematic separation of animals based on their physiological status. This preventative measure seems to work, as theft accounted for 23% of stock losses, which is lower than the 52% reported by Collins-Lusweti (2000) in South African village goats and 40% reported by Monau *et al.* (2017) for Tswana goats in Botswana.

In the present study purchasing was the main way of acquiring goats, corroborating findings from previous studies conducted in some African countries (Assan & Sibanda, 2014; Byaruhanga *et al*., 2015; Dossa *et al*., 2015). Goats were also acquired via government programs in the Michangulene village. Most farmers used their own breeding buck(s) for natural breeding although farmers in Mahelane village relied on a communal breeding buck. Regardless of the source of the male, uncontrolled breeding took place. Breeding bucks were used for mating from as young as 6 to 12 months. As soon as males reached puberty, they were free to mate as all animals' graze together. The lack of structured breeding systems and appropriate infrastructure, such as paddocks, as well as limited knowledge regarding herd management facilitate does and bucks run together all year round (Rumosa Gazwe et al., 2009). A lack of controlled breeding results in inbreeding and no fixed kidding seasons (Monau *et al*., 2017) compounding the poor management as kids are born throughout the year.

A male is usually kept within a production system for between 2 to 4 years, after which they were slaughtered for meat or sold. The age at first kidding of 12 to 18 months reported by the majority of farmers, was similar to that reported for the Mashona breed (16-18 months) in Zimbabwe (Ndlovu & Royer, 1988) and the Nguni breed (16-18 months) in South Africa (Webb & Mamabolo, 2004). Earlier ages between 6 and 12 months were also reported in this study, which can be expected in traditional management systems where bucks run continuously with does (Chukwaka *et al*., 2010). Kidding intervals of 6-8 months for goats reported across the study villages were in line with results reported by Webb & Mamabolo (2004) for Nguni goats in South Africa. The longer kidding intervals reported in the Michangulene and Mahelane villages, corresponds with that reported by MacKinnon and Rocha (1985), Wilson (1989) and Rumosa Gwaza *et al*. (2009). A large variation in kidding intervals are associated with traditional management systems where random mating and continuous mating throughout the year is common (Chukwaka *et al*., 2010).

Droughts, theft and diseases are commonly reported as major constraints to rural goat farming (Collins-Lusweti, 2000; Monau *et al*., 2017). Health problems were frequent during the rainy season in which diarrhoea was most prevalent. The occurrence of diarrhoea can be attributed to grazing on regrowth of natural vegetation with high moisture content and nutritive value, after periods of scarcity and poor quality vegetation during the dry season (Payne, 1990). Respiratory disorders and ticks were also frequent, indicating poor or lack health management limited or non-existent veterinary assistance in the study areas. Similar findings were described in other studies (Devendra & McLeroy 1982; Kusiluka & Kambarage, 1996; Nsereko *et al*., 2015; Onzima *et al*., 2017), who reported gastrointestinal, infection diseases on extensive systems with limited veterinary assistance.

Culling of goats was a common practice among goat farmers across the study villages. Old age and temperament were the main reasons for culling male goats from the flock. This is not in agreement with previous studies conducted in Ethiopia (Demissie *et al.,* 2014; Seid *et al.,* 2015) and West Africa (Dossa *et al*., 2015), where health problems were the main reason for farmers to cull goats, irrespective of their sex. However, in the present study, poor fertility and old age were the main causes for culling female goats, which is in agreement to the findings reported in Kenya (Bett *et al.,* 2009).

This study has been limited by the low number of respondents inquired, due to several challenges for data collection in the rural villages. These include a lack of understanding of the benefits of a survey for goat keepers, the limited number of possible participants and their unavailability during the cropping season as they prioritize farm activities. Furthermore, smallholders do not have any phenotypic records on the productive and reproductive parameters of their animals, making it very difficult to provide data to inquirers.

Similar numbers of households per village were used in surveys of goat production in South Africa by Cullins-Lusweti (2000) and Mdladla *et al.* (2017). As baseline data for goat production is virtually non-existent in the rural regions of Mozambique, these findings will contribute to future research and assist in baseline knowledge.

Conclusions

Goat production plays an important role in the livelihoods of rural Mozambican farmers. It is comprised of indigenous goats reared under extensive system, browsing natural pasture throughout the year. Although the goats are hardy and well adapted to local conditions, their production is limited by poor nutrition, a lack of management and a high prevalence of diseases and parasites. Therefore, there is a need for appropriate intervention strategies to improve goat production, through education of farmers on good husbandry practices, such as better breeding and feeding practices as well as disease control strategies. Also, the baseline information provided in this study will contribute in the development of coordinated and comprehensive goat production improvement programs and ultimately improve goat productivity and the livelihood rural farmers.

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CHAPTER 4

SEASONAL VARIATION IN THE COMPOSITION OF NATURAL FODDER IN THE CHANGALANE DISTRICT OF MOZAMBIQUE

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Abstract

This study aimed to provide baseline data on the changes in nutritive value of natural fodder over a one year period in a district of southern Mozambique. Samples of eight key native species consumed preferentially by goats, namely *Sclerocarya birrea*, *Morus alba*, *Spirostachys africana*, *Dichrostachys cinerea*, *Flueggea virosa*, *Acacia nigrescens*, *Acacia nilotica* and *Panicum maximum*, were collected and analysed for their key nutrient constituents, after which the daily energy, crude protein, calcium and phosphorus intake of goats were estimated. Both the daily energy intake (4.27 ± 0.17 MJ/kg DM vs. 3.71 ± 0.41 MJ/kg DM) and CP intake (92.83 ± 16.05 g DM/head/day vs. 59.38 ± 13.12 g DM/head/day) were higher in the rainy season than in the dry season. The daily intake of Ca and P did not show significant ($p > 0.05$) seasonal variations and were below the requirements for maintenance of a 20 kg goat during the dry season and for a pregnant goat during both seasons. Results of this study showed the need to supplement goats in Changalane district in Southern Mozambique with energy, protein and phosphorus for maintenance, growth and reproduction during the dry season.

Keywords: goats, intake, natural fodder, requirements

Introduction

Goats are one of the most economically and socially important livestock species in developing countries (Simela and Merkel, 2008). They play an important role in the lives of small-scale farmers, providing meat and cash flow. They are used during festive and ceremonial occasions and are sometimes milked for home consumption (Garrine *et al.*, 2010; Hossain *et al.*, 2015; Ouchene-Khelifi *et al.*, 2015).

The global goat population is currently estimated at one billion, of which 95% are meat goats (Thompson, 2006). Mozambique has approximately 3.9 million goats (FAOSTAT, 2017), of which almost 97.7% belong to small-scale farmers and less than 1% are farmed intensively (National Institute for Statistics, 2014). The two main types of goats in Mozambique are the Landim and Pafuri breeds, which are described as meat goat breeds (Garrine *et al.*, 2010).

In Mozambique most goats are used for meat production with an estimated annual meat production of 2.1 thousand tonnes (Morgado, 2000; Maciel *et al.*, 2004; National Institute for Statistics, 2014).

In the subtropical climatic zones of Mozambique, the low quantity and quality of natural pasture in the dry season (May–September) are major obstacles to livestock production (Faftine *et al.*, 1998). However, owing to the poor quality of pastures in the dry season, animals may lose up to 40% of their body weight (Clariget *et al.*, 1998). This affects the production of dairy, beef and mutton industries significantly (Abdalla *et al.*, 1999; Lusweti, 2000). Sufficient plant biomass must be carried over from the wet season to feed the domestic livestock population during the long dry season (Bakshi and Wadhwa, 2007).

Goats are generally more effective browsers and have a better ability than cattle and sheep to utilise woody species and low-quality forages (Tisserand *et al.*, 1991; Silanikove, 2000; Salem *et al.*, 2004; Provenza, 2008). However, they are still affected by the adverse effects of the dry season. In a previous study conducted in Mozambique, it was reported that cattle and goats fed on tropical native pastures and crop residues such as maize stover lost more than 20% of their body weight during the dry season (Faftine *et al.*, 1998). This weight loss has negative economic repercussions, as it affects the physical condition of adult animals, thereby reducing the rate of conception and consequently the number of births, as well as stunting the growth of young animals that may result in mortality (Cronjé, 1990; Mahusoon *et al.*, 2004; Rumosa Gwaze *et al.*, 2009).

The quality and availability natural pasture species and levels of nutrients show great seasonal variation (Bakshi and Wadhwa, 2007). Additionally, the quality of natural pasture during the dry season does not sustain the energy and nitrogen requirements of ruminants for maintenance and pregnancy (Silanikove *et al.*, 1986). Thus, there is a need for understanding the availability of nutrients as part of the ingested diet during the different season visa vis the requirement of the goats in order to recommend supplementation of deficient nutrients to improve production (Van Soest, 1987).

Thus, information regarding the year-round nutritive value of native pastures is crucial. In Mozambique, such baseline data are lacking and studies aimed at assessing the quality of natural grazing have not been conducted.

This study aims to characterise the nutrient composition of key species in a grass and shrub used for browsing over a one-year period and to assess the year-round variation in diet quality for goats in Changalane district.

Materials and methods

This study was carried out over one year (2013) at the University Centre of Changalane, which is located approximately 75 km from Maputo (26º 17' 29" S, 32º 11' 23" E) at an altitude of 104 m. The climate is semi-arid with an average rainfall of 476.9 mm per annum. The rainy season lasts from October to April and the dry season from May to September. The annual average temperature is 23.2 ºC. The highest average temperature (32.1 ºC) occurs in December and the lowest (12.3 ºC) in June (National Institute of Meteorology, 2012–2013). The area included in the study is classified as semi-arid, with noticeable land degradation owing to lack of proper management, mainly caused by overgrazing and uncontrolled fires (Timberlake and Jordão, 1985). This area has traditionally been used for grazing of various livestock species (e.g. cattle, sheep and goats). No structured grazing system is followed, nor is there a limit to the number of animals grazing at a given time.

The goats were ear tagged and de-wormed against gastrointestinal nematodes and external parasites by subcutaneous injection with Ivermectin at a dose of 1 ml/50 kg live weight. Goats were reared under an extensive production system and were allowed to graze freely in open access grazing areas during the day and housed at night in kraals made of conventional material. Boreholes were used to provide water *ad libitum* for the goats in both seasons.

The vegetation of the Changalane Administrative Post area is characterised by grasses, shrubs and trees. Figure 4.1 and 4.2 shows the typical vegetation in dry and rainy seasons. The following grass species predominate, namely *Themeda triandra, Panicum maximum, Andropogon gayanus, Eragrostis spp, Digitaria spp, Urochloa mosambicensis, Setaria sphacelata, Stylosanthes mucronata, Brachiaria deflexa, Commelina benghalensis and Cymbopogon excaravatus* (José, 2003). The most common species of shrubs are *Dichrostachys cinerea, Acacia natalitia, Acacia nigrescens, Maytenus senegalensis, Gossypium herbaceum, Eriosema palviflorum, Indigofera pulchra;* and predominate trees are *Sclerocarya birrea, Conbretum zeyheri, Acalypha villlicaulis, Ipomea oblongata; and Ziziphus mucronata* (Rocha *et al.,* 1991; José, 2003).

Figure 4.1 Typical vegetation of grass and shrub during the dry season with uncontrolled fire (Source: Owner, 2019)

Figure 4.2 Typical vegetation of grass and shrub during the rainy season (Source: Owner, 2019)

For this study, samples of native species most commonly consumed by goats were collected once a month from February 2013 to December 2013. The month of January, however, was not included owing to limitations in resources. Direct observation was used to determine the species composition of the diet consumed by the goats. Animals grazed approximately six hours per day at Changalane Experimental Centre, under permanent supervision for security reasons. Each month, three goats were observed individually for five consecutive days by the researcher alongside two technical assistants, who observed their bite rate (biting), species preferences and subsequently identified the most frequently consumed shrubs and grasses. These observations were done while keeping a reasonable distance from the animals so as not to alter their grazing behaviour. These records were used to determine the percentage contribution of each species as part of their daily dietary consumption.

A sample of 200 g of grass were harvested at mature stages of growth and chopped to 2 - 3 cm in length. The same amount of leaves and branches from trees fodder and shrubs was harvested was harvested at mature stages of growth. Then were sent to the Nutrition Department of the Faculty of Veterinary in Maputo, where they were stored in plastic bags and kept at 5 ^{o}C in refrigerator. This was made in weekly basis to obtain a composite representative sample. The composite representative sample was sent to the UP-Nutrilab (University of Pretoria), to determine the nutrient composition. A dry matter intake (DMI) of 550 g DM/head/day was assumed and thus subsequently used to determine nutrient intake levels for a 20 kg (average weight of a mature indigenous goat) that assumed to consume 3% of DM of its body weight (Rodrigues *et al.*, 2013). Daily metabolisable energy (ME), crude protein (CP), calcium (Ca) and phosphorus (P) intakes were calculated based on the following methodology:

1. The estimation of the daily intake of various species of shrubs and grass was performed by direct observation of the goats in order to determine preferential consumption of the species and subsequently to rank them as most or least preferred, based on the percentage composition of key species.
2. Data on the percentage daily intake of each shrub were calculated as follows:
   a) ME concentration was calculated by converting the GE values using the following standard formula: *ME (MJ/kg DM) = 0.82 x (GE x IvDOM)*, where the GE and *IvDOM* results were obtained from the laboratory analysis (Tilley and Terry, 1963).
   b) The content of CP (AOAC 968.06), Ca (Giron, 1973) and P (AOAC 968.17) for key species were obtained from the laboratory analysis results and were obtained using the methods recommended by AOAC (2000).

Daily intake of energy, protein, Ca and P were calculated using the following equations:

$$Daily\ energy\ intake = DMI\ (g) \times \left(\sum_{i=1}^{n} \%DI(i) \times ME(i)\right) \qquad \text{(Equation 1)}$$

$$Daily\ protein\ intake = DMI\ (g) \times \left(\sum_{i=1}^{n} \%DI(i) \times \frac{CP(i)}{100}\right) \qquad \text{(Equation 2)}$$

$$Daily\ calcium\ intake = DMI\ (g) \times \left(\sum_{i=1}^{n} \%DI(i) \times \frac{Ca(i)}{100}\right) \qquad \text{(Equation 2)}$$

$$Daily\ phosphorus\ intake = DMI\ (g) \times \left(\sum_{i=1}^{n} \%DI(i) \times \frac{P(i)}{100}\right) \qquad \text{(Equation 3)}$$

Where:

DMI: average daily consumption of the goats expressed as DMI

n: represents the number of grass and shrubs under consideration (n = 8)

%DI(i): percentage proportion of each shrub or grass in the DMI

ME(i): ME content of each shrub or grass obtained from DM basis analysis

CP(i): CP content of each shrub or grass obtained from DM basis analysis
Ca(i): Ca content of each shrub or grass obtained from DM basis analysis
P(i): P content of each shrub or grass obtained from DM basis analysis

The calculated results of daily intake of ME, CP, Ca and P were compared with the requirements of goats for maintenance and early gestation with a single kid (NRC, 2007). The data on dietary chemical composition and intake were analysed with the descriptive statistics procedure in Statistics Version 8.0. The comparison of nutrient intake between seasons was performed using the student *t*-test, considering a significance level of 0.05 (Kaps and Lamberson, 2004).

Results

Observation of biting behaviour showed that the most frequently consumed species over the year ranked as a percentage of daily intake**,** were a combination of six shrubs *Dichrostachys cinerea* (17.65%), *Spirostachys africana* (17.65%), *Flueggea virosa* (17.65%), *Acacia nigrescensn* (11.76%), *Acacia nilotica* (5.88%), *Sclerocarya birrea* (11.76%); one grass species *Panicum maximum* (11.76%) and one fodder tree *Morus alba* (5.88%). *Morus alba* is a fodder tree cultivated at the University Centre. Other grass species such as *Setaria verticillata*, *Botriochloa insculpta*, *Heteropogon contortus*, *Urochloa mosambicensis*, *Themeda triamda*, *Cynodon dactylon*, *Sorghum halepenses*, *Aristida sp*, *Eragrostis tenella* and *Cenchrus ciliaris* were not included in the study as they were not among the most preferred by goats. Table 4.1 shows the percentage of preferred species ingested by goats as part of their daily DMI over the one-year period. The level of intake per species varied depending on the growth of the species and palatability during the year. It was observed that goats ate *Dichrostachys cinerea* and *Spirostachys africana* predominantly throughout the year, followed by *Flueggea virosa, Acacia nigrescens* and *Panicum maximum* at certain periods.

Table 4.1 Percentage of preferred species ingested per **month by goats as part of daily DMI over one year**

Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
D. cinerea	23.62	16.79	16.79	21.45	20.86	18.97	11.49	26.10	15.23	23.50	23.76
S. Africana	34.65	29.79	29.79	15.96	18.82	22.91	25.13	26.43	32.79	14.10	16.86
F. virosa	9.30	0.38	0.38	14.61	17.38	17.32	-	9.28	13.52	11.46	15.65
A. nigrescens	3.81	22.75	22.75	12.05	12.73	16.23	17.33	7.10	9.49	15.39	14.79
A. nilotica	5.27	6.02	6.02	6.30	6.96	6.01	12.1	7.25	11.19	11.70	6.87
S. birrea	8.40	8.92	8.92	9.31	9.78	7.11	8.87	6.34	7.72	11.77	10.43
M. alba	2.03	7.90	7.90	4.57	5.10	4.40	5.88	2.80	3.11	5.88	5.50
P. maximum	12.92	7.45	7.45	15.75	8.38	7.05	19.2	14.70	6.95	6.20	6.14
Total	100	100	100	100	100	100	100	100	100	100	100

The results of the chemical composition (ME, CP, Ca and P) analysis of each key species for each month are summarised in Table 4.2. Among the eight preferred species, CP levels varied from 3.45 to 31.92 g/100 g DM throughout the year. *Flueggea virosa* showed the highest levels of CP during the rainy season, and for *Morus alba* during the dry season. Metabolisable energy values of the key species in the dry season varied from 3.40 MJ/kg DM in *Sclerocarya birrea* to 11.82 MJ/kg DM in *Acacia nilotica* while in the rainy season varied from 3.50 MJ/kg DM in *Sclerocarya birrea* to 11.01 MJ/kg DM in *Flueggea virosa*. Calcium levels in *Sclerocarya birrea* in the dry season were 0.22 g/100 g DM and in *Panicum maximum* during the rainy season were 0.32 g/100 g DM. Phosphorus levels ranged from 0.04 to 0.59 g/100 g DM, with the lowest value observed in *Dichrostachys cinerea* and the highest in *Flueggea virosa* both in the rainy season.

Table 4.2 Monthly chemical composition of key species selected by goats over 11 months period in Changalane district, Southern Mozambique (2013)

Parameter	Species	Month										
		Feb	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
CP(g/100g DM)	***D. cinerea***	19.04	17.29	12.44	12.08	10.44	9.37	10.65	8.56	18.30	20.07	18.99
	S. africana.	12.56	11.10	11.93	10.03	9.63	6.91	9.15	7.30	8.30	23.67	15.83
	F. virosa	16.00	18.21	19.61	15.67	no	no	no	25.03	22.91	31.92	20.37
	A .nigrescens	19.19	20.10	19.76	15.31	15.88	12.44	14.65	21.51	21.32	19.01	18.95
	A. nilotica	15.98	15.92	16.35	12.67	14.53	10.39	11.50	9.65	11.24	15.25	15.33
	S. birrea	11.16	11.99	10.32	9.09	7.68	11.18	4.92	13.39	12.14	14.49	10.71
	M. alba	18.06	25.62	17.34	16.82	15.90	16.73	22.39	31.89	29.44	26.70	21.79
	P. maximum	9.22	10.89	7.19	9.25	12.82	10.10	13.75	3.45	14.54	22.26	15.32
ME(MJ/kgDM)	***D. cinerea***	6.05	5.97	4.03	4.93	5.09	5.50	5.48	6.89	5.54	6.05	5.38
	S. africana.	9.67	8.69	9.67	9.20	9.88	8.49	8.98	7.63	7.12	10.24	9.81
	F. virosa	9.33	10.66	11.01	10.78	no	no	no	10.57	10.99	10.34	9.89
	A. nigrescens	5.90	5.90	6.55	6.74	7.19	6.22	6.19	6.43	6.46	5.76	5.68
	A. nilotica	10.73	10.00	9.47	11.23	11.82	7.69	10.05	10.23	9.72	8.14	7.98
	S. birrea	3.50	5.02	3.74	3.51	3.40	10.26	8.13	4.84	6.02	5.87	4.41
	M. alba	9.18	10.88	9.53	8.93	9.11	8.04	9.71	10.79	10.44	10.19	9.09
	P. maximum	8.02	6.98	5.60	6.23	7.41	7.89	8.15	5.25	8.42	9.71	9.13

Parameter	Species	Month										
		Feb	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Ca (*g/100g DM*)	***D. cinerea***	1.54	1.57	0.54	1.14	2.19	2.53	2.53	1.08	0.93	0.99	1.70
	S. africana.	1.67	2.90	2.90	1.92	2.78	3.28	3.28	3.21	2.56	0.56	1.17
	F. virosa	1.15	1.65	1.83	1.46	No	no	no	1.14	2.33	1.48	1.17
	A. nigrescens	1.42	0.81	1.20	2.15	2.33	2.21	2.21	0.59	1.03	0.95	1.18
	A. nilotica	0.66	1.19	0.73	0.99	2.15	1.14	1.14	0.87	0.48	0.48	1.13
	S. birrea	1.41	2.11	2.65	1.79	0.67	0.22	0.22	1.05	1.11	1.74	1.70
	M. alba	2.74	1.97	3.05	3.13	3.54	2.97	2.97	2.31	2.18	2.77	3.10
	P. maximum	0.32	0.32	0.34	1.10	0.68	0.52	0.52	0.45	0.49	0.53	0.49
P (*g/100g DM*)	***D. cinerea***	0.15	0.17	0.04	0.10	0.15	0.09	0.09	0.14	0.13	0.25	0.19
	S. africana.	0.17	0.12	0.12	0.11	0.11	0.10	0.10	0.10	0.10	0.49	0.19
	F. virosa	0.16	0.19	0.16	0.15	No	no	No	0.28	0.28	0.59	0.24
	A. nigrescens	0.16	0.24	0.19	0.12	0.30	0.06	0.06	0.16	0.16	0.11	0.20
	A. nilotica	0.14	0.14	0.12	0.09	0.14	0.13	0.13	0.14	0.13	0.24	0.16
	S. birrea	0.13	0.14	0.11	0.10	0.29	0.17	0.17	0.29	0.28	0.21	0.15
	M. alba	0.19	0.43	0.17	0.20	0.34	0.32	0.32	0.42	0.42	0.49	0.26
	P. maximum	0.21	0.22	0.16	0.21	0.34	0.21	0.21	0.33	0.33	0.28	0.23

no:no leave

The daily intakes of ME, CP, Ca and P are presented in Figure 4.3. There was significant ($p < 0.05$) seasonal variation in daily energy intake, with the highest intakes being observed in the rainy season (4.27 ± 0.17 MJ/kg DM) compared to the dry season (3.71 ± 0.41 MJ/kg DM). Energy requirements for the maintenance of goats were only met during the rainy season, while for pregnancy were not met throughout the year (Figure 4.3A). The daily intake of CP, though with significant ($p < 0.01$) seasonal variation, was above the daily requirement for maintenance throughout the year, with estimated average intakes of 92.83 ± 16.05 g DM/head/day and 59.38 ± 13.12 g DM/head/day in the rainy and dry season, respectively, whereas it was 6% below the requirement for gestation in the dry season (Figure 4.3B). Natural fodder provided sufficient daily intakes of Ca over the year, with average intakes 7.04 and 4.8 g DM/head/day above the requirement for maintenance and gestation, respectively (Figure 4.3C). The daily P intake was slightly below the requirement for maintenance of a 20 kg bodyweight goat during the dry season and significantly deficient for pregnant does in almost all seasons (Figure 4.3D).

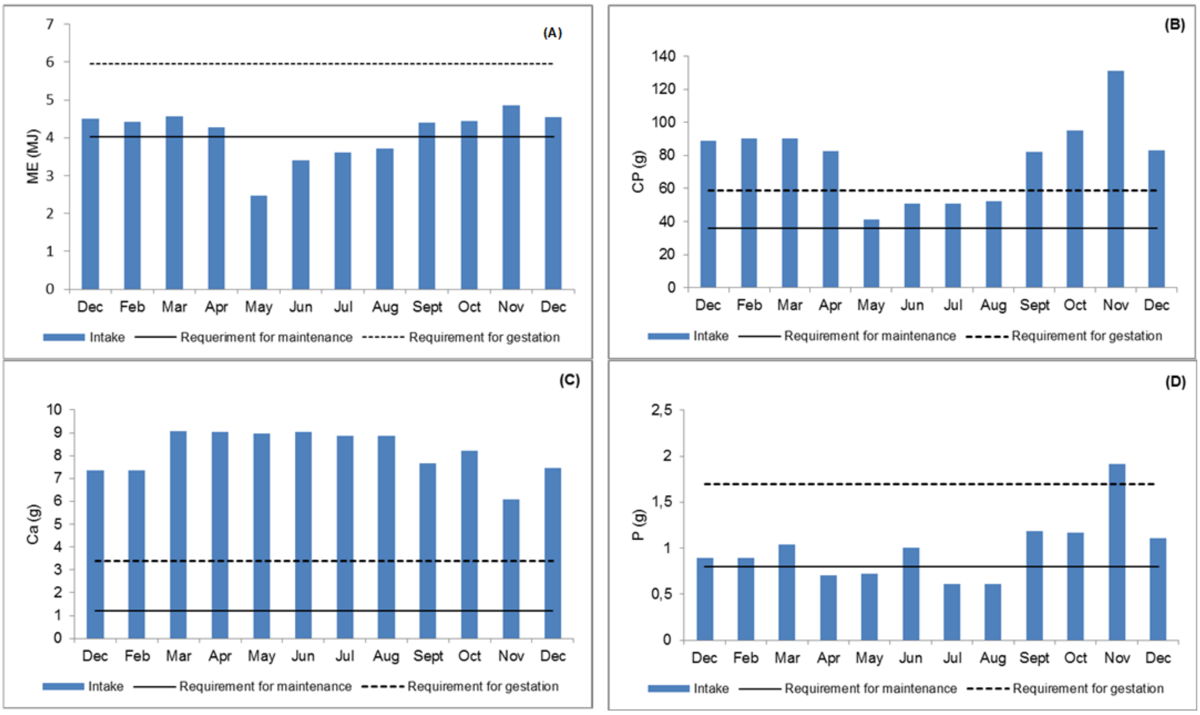

Figure 4.3 Daily requirements vs. daily intake of ME (A) CP (B), Ca (C) and P (D) for goats grazing in the selected forage species over 12 months period in Changalane district, Southern Mozambique (2013)

Discussion

The exact determination of the daily intake of ME, CP, Ca and P for grazing animals is a complex process, as nutrient intake depends on several factors such as the variability in the types of shrub and leaves of trees that are consumed, grazing times and the preferences of animals during grazing (Rodrigues *et al.*, 2013). For this reason, the values presented in this study represent an estimate which can be used as a broad benchmark of the availability of species and their nutritive value in Mozambique. In general, this study showed variations in the estimated daily intakes that were associated with seasonal changes in the quantity and quality of natural fodder. The diversity of preferred species in the study area did not provide sufficient nutrients to meet reproductive needs of goats over the year. The energy intake by the goats over the rainy season satisfied only the maintenance requirements of the goats. Similar results have been reported in previous studies by various authors (Silanikove, 1986; Van Soest, 1987; Faftine *et al.*, 1998), who showed that natural pastures in semi-arid regions contain sufficient nutritive value to sustain growth and the maintenance requirements of goats during the rainy season but not during the dry season. The deficit of ME intake over the year for gestating goats has an adverse effect on reproduction efficiency as it adversely influences the birth weight of kids and low weight at birth often results in a high observed mortality rate (McKinnon and Rocha, 1985; Cronjé, 1990).

The daily CP intake estimated in this study met the maintenance requirements of goats but not during the dry season for mature does in gestation. This could be due partly to a shortage of forage during the dry season and partly to the poor quality of the forage available, which is often fibrous and low in protein. Comparable findings were reported in previous studies conducted in semi-arid areas (Ben Salem and Smith, 2008). This deficit in CP intake for pregnant goats would lead to decreased body weights, frequent abortions and even death of animals (McKinnon and Rocha, 1985; Cronjé, 1990). Furthermore, does under nutritional stress give birth to kids with reduced birth weights and produce a limited amount of milk, leading to a high rate of pre-weaning mortalities (McKinnon and Rocha, 1985). The poor nutritional status could predispose the kids to the effects of non-nutritional factors that cause mortality, such as parasitic diseases (for example, ticks - Ricktsiose, Babesiosis), as well as bacterial diseases (Brucellosis, Tuberculosis) that are common in Mozambique (Timberlake and Jordão, 1985).

The daily intake of Ca exceeded the requirements of goats throughout the year, with intakes ranging from 6.07 to 9.05 g DM/head/day. The high intakes of Ca may reflect the high concentrations of this mineral in the soil (White and Broadley, 2003), since it tends to accumulate in plants during periods of drought (McDonald *et al.*, 1988) and become highest in the leaves during the rainy season (Tuna *et al.*, 2004), a situation that may be similar to the present study area. Conversely, the maintenance requirements for P was only met during the rainy season, but not during the dry season. Regardless of the season, the P requirements of mature does in reproduction were not met. The lower P values observed may be associated with P deficiency in the soils or fluctuations in its availability. Nevertheless, some authors (Bogin, 1992; González and Scheffer, 2002) reported that ruminants are well adapted to compensate for the common ratio of high Ca to P (up to more than 3:1) in natural pastures. Supplementation with excesses of Ca and P, however, may cause decreased intestinal absorption of other minerals such as Magnesium (Mg), Zinc (Zn), Manganese (Mn) and Copper (Cu) (Bogin, 1992).

This study revealed a decrease in the quality of natural fodder, specifically in terms of energy, protein and P intake during the dry season. Several authors have reported adverse effects on livestock of poor quality vegetation during the dry season, including loss of body weight, low body condition scores and high mortality rates (Clariget *et al.*, 1998; Cronjé, 1990; Faftine and Zanetti, 2010). Furthermore, the 'feed gap' that coincides with dry periods, when forage or natural pasture growth is non-existent or low in quantity and quality, is a common problem in extensive goat production systems in Southern Mozambique regions (Morand-Fehr, 2005; Blache *et al.*, 2008). To minimise the effects of these factors there is a need to provide animals with supplementation during the harsh dry periods and more research in this area is needed to address the challenges of introducing low-cost feeding and supplementation alternatives, viable for use by smallholder and subsistence producers.

Conclusion

This study was aimed to assess the key species and year-round variation in diet quality (intake ME, CP, CA and P) of natural fodder grazed by goats in the Changalane district of Southern Mozambique. Results indicate that there are variations in intake of nutrients and the contributions of different species in the diet of goats grazing the natural fodder. There is a decrease in the quality of natural fodder during the dry season and this is associated with lower intake of energy, protein and phosphorus. Hence, there is a need to supplement the goats utilizing the selected species with energy, protein and phosphorus mainly during the dry season to meet the nutrient requirement for maintenance and reproduction.

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CHAPTER 5

IMPACT OF SUPPLEMENTATION OF *MORINGA OLEIFERA* AND *LEUCAENA LEUCOCEPHALA* TREE FODDER ON THE PRODUCTION OF INDIGENOUS GOATS IN MOZAMBIQUE

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Impact of supplementation of *Moringa oleifera* and *Leucaena leucocephala* tree fodder on the production of Indigenous goats in Mozambique

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Abstract

This study was conducted to assess the effect of supplementation with *Leucaena leucacephala* (LL), and *Moringa oleifera* (MO) tree leaves on growth and reproduction performance of indigenous goats in southern Mozambique. Fifty-six indigenous goats with an average age of 8 months and a body weight of 17.57 ± 3.97 kg were randomly divided into seven treatments groups of 4 castrated males and 4 females each. Treatment 0 served as the control group (Co), and these animals only grazed on natural pasture without any supplementation. In addition to the natural pasture, three groups received 50 g (LL_{50}), 75 g (LL_{75}) and 100 g (LL_{100}) of *L. lecocephala* dried leaves, respectively while groups 4 to 6, received 40 g (MO_{40}), 60 g (MO_{60}) and 80 g (MO_{80}) of *M. oleifera* dried leaf meal, respectively. *Leucaena leucocephala* contained 23.7% crude protein (CP) and 11.05 MJ/kg DM of metabolizable energy (ME), while *M. oleifera* leaves contained 28.8% CP and 7.61 MJ/kg DM of ME. The study lasted for 16 months from July of 2015 to November of 2016. Compared to the control, treatment supplementation of the tree leaves, irrespective of level, had a significant effect ($p < 0.05$) on the overall body weight gain and the final body weight of the bucks but did not significantly affected the does ($p > 0.05$). No difference could be detected between the final body weight and overall average daily gain ($p > 0.05$) based on the supplementation source (*Leucaena Lecocephala* versus *Moringa oleifera* dried leaf). Average daily gain (ADG), during the dry season, ranged from -7.85 to 10.42 g/head/day for goats fed LL leaves and from -7.92 to 13.33 g/head/day for goats fed MO and these values were higher ($p < 0.05$) compared to values recorded for the control goats (-36.11 to -20.74 g/day). All female reproduction efficiency parameters measured such as birth rate, twinning rate, birth weight and weaning were significantly ($p < 0.05$) higher in supplemented goats compared to the control goats. Body weights at birth and weaning weight of the offspring of supplemented goats were however not significantly ($p > 0.05$) affected by supplementation. The highest survival rate (100%) was observed in goats supplemented with *Moringa oleifera* (MO_{40}), while the lowest was recorded in goats supplemented with *Leucaena leucocephala* leaves (LL_{75}). The results of this study suggest that *L. leucacephala* and *Moringa oleifera* tree leaves could be used as supplementation to goats to overcome the adverse effects of seasonal fluctuations in feed quality on growth and reproductive performance.

Keywords: Fodder trees, Growth, Reproductive, Smallholder, Goats, Supplementation

Introduction

The global goat population has increased during the last decade and currently exceeds 1 billion goats with approximately 95% of those found in developing countries (FAOSTAT, 2014). Goats play an essential role for the smallholder farmer, mainly as a source of income and animal protein (Osaer et al., 1999; Peacock, 2005), but also contributing to the livelihoods of the poor through risk mitigation and accumulation of wealth (Casey and Webb, 2010; Hossain et al., 2015; Ouchene-Khelifi et al., 2015).

In the (sub)tropics, goat farming is limited by several factors which adversely affect its productivity. Nutrition, based mainly on natural pasture, poses the most severe problem since the composition of natural pasture species and levels of nutrients show significant seasonal variation (Hove et al., 2001; Berihu et al., 2015). During the dry season (April to September), the natural pasture becomes scarce and poor in quality and consequently does not sustain the energy and nitrogen requirements of ruminants for maintenance and other physiological functions (Silanikove et al., 1986; Oni et al., 2010). Due to poor nutrition goats may lose up to 20 – 40% of the body weight (Clariget et al., 1998; Faftine and Zanetti, 2010), have reduced performance and productivity (Lusweti, 2000) and become more susceptible to diseases (Kanani et al., 2006).

Supplementation during the dry season represents a valuable economic alternative to improve the quality of diet and reduce nutritional problems for smallholder goat production compared to purchased concentrates or agro-industrial by-products (Getu, 2006; Kanani et al., 2006;

Place et al., 2009). In Mozambique, the alternative feed resources available in communal zones include crop-residues from maize, rice, cowpea and groundnut (Preston, 1987; Faftine and Zanetti, 2010). Moreover, supplementation with cultivated legumes such as *L. leucocephala* has been studied in the feeding system of goats (Muir and Massaete, 1996; Faftine and Zanetti, 2010). Fodder trees and shrub forages are considered to be good and cheap sources of protein and micronutrients that can be used to increase the quality and availability of feeds for ruminants during the dry season (Manaye et al., 2009; Moyo et al., 2012; Bebeker and Abdalbagi, 2015, Babiker et al., 2017). It has multiple advantages for resource-poor smallholder farmers as it can be grown locally, propagated efficiently and are less demanding regarding the use of fertilisers, pesticides or advanced technology (Mendieta-Araica et al., 2011).

Leucaena leucocephala and *Moringa oleifera* are important sources of energy and protein in the tropics. *Leucaena leucacephala* is a drought-resistant leguminous tree (Devendra and Burs 1993), and its leaves are readily consumed and nutritious (Yami et al., 2000). It provides highly nutritious forage with an average crude protein content of 237g/kg of dry matter (Damothiran and Chandrasekaran, 1982; Kanani et al., 2006), but its use as feedstuff for livestock is limited by the presence of the toxic amino acid, mimosine. However, *L. leucocephala* has been used to feed ruminants without adverse effects because of the presence of ruminal micro-flora capable of degrading mimosine (Kanani et al., 2006). In tropical agroforestry systems, it is frequently used for a variety of purposes including as provision of forage and shade for livestock, fuelwood, soil stabilisation and fertility improvement (Kang et al., 1984; Brewbaker, 1987). When intercropped in a pasture forage program, it can provide a balanced diet of protein and carbohydrates derived from the grasses (Robert et al., 1996). Its potential benefits on goat production have been confirmed in studies conducted in tropical regions, which reported improvements in body weight gain when it was used as a supplement to poor pasture (Aletor and Omodara 1994; Kanani et al., 2006; Rubanza et al., 2007; Mohamed et al., 2015).

Moringa oleifera is an ideal protein supplement for livestock that can be quickly grown, even under drought condition (Oduro et al., 2008). Its leaves are nutritious with a crude protein content ranging from 225 to 400 g/ kg DM, and it has therapeutic and prophylactic properties (Moyo et al., 2011). This fodder tree is also rich in vitamins A, B and C, and contain a higher level of calcium than milk (Fahey, 2005; Midcap and De Witte, 2006; Mendieta-Araica et al., 2011; Gopalakrishnan et al., 2016). *Moringa oleifera* seems to be readily accepted by animals, and no toxic effect from its use has been reported. Sánchez et al. (2005, 2006) showed the beneficial effects on intake, digestibility, milk production and composition of dairy cows fed different levels of foliage of *M. oleifera.* Several other studies conducted to investigate the use of *M. oleifera* as a source of protein in goats also reported improvements in feed intake, nutrient digestibility, growth performance and milk yield. This suggests that *M. oleifera* could be used as a low- cost alternative protein supplement for goat production (Kanani et al., 2006; Asaolu et al., 2011; Moyo et al., 2012; Bebeker and Abdalbagi, 2015; Kholif et al., 2018).

The use of locally available fodder trees and shrub forages represents a useful and cost-effective source of protein and micronutrients for goats. In Mozambique, the use of these alternative feed resources for goats is poorly documented and has not been disseminated among smallholder farmers. This study aimed to evaluate the effect *L. Leucocephala* and *M. oleifera* leaves supplementation, during the dry season, on indigenous goat production in a subtropical environment in southern Mozambique.

Material and Method

Study Setting

The study was conducted at the University Center of Changalane, located in the district of Namaacha, in the Maputo province of southern Mozambique. The Namaacha district covers an area of 2196 km^2 and is characterized by a humid tropical climate with an average annual rainfall of 751 mm. However, the district has been experiencing a substantial decrease in rainfall over the last few years, having received an annual rainfall of only 260 mm in 2015 and 471 mm in 2016 (National Institute of Meteorology of Mozambique, 2015-2016).

Most parts of the district are classified as semi-arid, with visible desertification due to poor management caused by overgrazing (MAE, 2005). In this district, the average maximum annual temperature varies between 23° and 24 °C, with maximum highs of 36 °C. The rainy season is from October to April and the dry season ranges from May to September.

Experimental Design

Pre-experimental period

Before the onset of the experiment, goats were ear tagged and de-wormed against gastrointestinal nematodes and external parasites. The goats were submitted to a 21-days adaptation period to feeding and housing and were allowed to graze during the daytime and access water *ad-libitum*.

Experimental period

Fifty-six 8-month-old indigenous goats, consisting of 28 females and 28 castrated males with an average body weight (BW) of 17.4 ± 0.7 kg were randomly selected and divided into seven groups of 8 animals each (4 females and four males). The groups were then randomly allocated to one of seven treatments consisting of a natural pasture diet combined with different levels of *L. leucocephala (LL)* or *M. oleifera (MO).* Treatment 0 served as the control group (Co) and consisted of a natural pasture diet with no supplementation. In Treatment 1 to 3, the goats grazed the natural pasture with daily supplementation of 50 g (LL_{50}), 75 g (LL_{75}) and 100 g (LL_{100}) of *L. leucocephala* leaf meal respectively. Treatments 4 to 6 included a daily supplementation of 40 g (MO_{40}), 60 g (MO_{60}) and 80 g (MO_{80}) of *M. oleifera* leaf meal to goats on natural pasture. Phosphorus deficit was covered by addition of a phosphorous salt for the *Leucaena leucocephala* and *Moringa oleifera* diet respectively.

Two bucks, previously selected and evaluated for their reproduction capacity (Nöthing, 2000) joined the females during the natural grazing period in order to guarantee mating.
During the dry season, the experimental groups were provided with the respective levels of supplementation at 8:00 in the morning before grazing. Each goat was fed its supplement in an individual box. The individual boxes fulfilled the welfare standards, and the quantities of supplement provided for each goat were adjusted monthly according to body weight. The experiment was conducted from July 2015 to November 2016.

Preparation of Leaf Meals

The leaves of *L. lecocephala* and *M. oleifera* were manually harvested from mature trees at the Boane district and Changalane village, in Maputo Province, during the summer period when they are more readily available. They were separated from branches cut from trees, air-dried under shade by spreading them on clean plastic sheets and turning several times for 72 h. Thereafter, the dried leaves were cut into small pieces and stored in sisal bags until use.

Chemical Analysis of the Feeding Diets

To establish the supplementation levels of *L. leucocephala* and *M. oleifera*, the dry and fresh forms of leaves were analysed to determine the metabolizable energy (ME), crude protein (CP), calcium (Ca) and phosphorus (P) content. The analyses were carried out at the UP *Nutrilab*, Department of Animal and Wildlife Sciences, Agricultural Sciences Building – University of Pretoria.

Traits measured

Growth performance

Goats were weighed at the beginning of the experiment and then fortnightly until the end of the experimental period using a commercial scale. Weighing was performed in the morning before supplementation was given. Average daily gain (ADG) was calculated by subtracting the initial body weight from the final body weight and divided by the number of experimental days.

Reproductive performance and growth performance of kids

The reproductive traits considered were the birth rate, litter size, twinning rate and survival rate. These traits were calculated as follow (Sen and Onder, 2016a);

Birth rate = (number of does giving birth/number of does mated) × 100

Litter size = (number of kids born/number of a does giving birth)

Twinning rate = (number of twin kids/number of does giving birth) × 100

Survival rate = (number of kids alive at weaning/number of kids alive at birth) × 100

All kids were weighed at birth to determine the birth weights and at four months of age to obtain the weaning weights.

Statistical analysis

Data were analysed using the statistical package SPSS release 20 (IBM Corp, 2011). Analysis of BW and ADG were performed using Analysis of Variance (ANOVA) for a completely randomised design, using the GLM procedure. Treatment and sex were entered into the model as independent variables while initial weight was considered as a linear covariate to control variation. When treatment effects were significant ($p < 0.05$) on the ANOVA, the effect of type and level of supplementation were determined by orthogonal contrast testing. A 5% significance level was adopted. The following statistical model was used: $Yij = \mu + Ti + \gamma j + \beta(xij - \bar{x}) + \epsilon ij$, where μ is the general mean effect, Ti is the effect of treatment, γj is the effect of sex, β is the linear regression coefficient, xij is the value of covariate variable, $\bar{x}$ is mean value of the covariate, and ϵij is the random error effect.

Results

The chemical composition of the feeder tree leaves

The chemical analyses of *L. leucocephala* and *M. oleifera* dried leaves on ME, CP, Ca and P are presented in Table 5.1. A higher concentration of CP and P was observed in *M. oleifera* than in *L. leucocephala* leaves, while on the contrary the observed ME and Ca was lower than that of *L. leucocephala*.

Table 5.1 Chemical analyses of *L. leucocephala* and *M. oleifera* dried leaves

Feeder trees	DM (g/100)	Nutrient contents (on Dry Matter basis)			
		ME (MJ/kg)	CP (g /100g)	Ca (g /100g)	P (g /100g)
L. leucocephala	100	11.05	23.70	3.26	0.15
M. oleifera	100	11.00	30.99	1.21	0.27

Growth performance

Table 5.2 presents the results of the growth performance of the goats throughout the study period. Final body weight was influenced by dietary supplementation with either *L. leucocephala,* or *M. oleifera* leaves. Generally, supplemented bucks had higher ($p < 0.05$) final

BW than control bucks. Although higher levels of *L. leucocephala* or and *M. oleifera* supplement showed higher weight gains compared to the control animals, the average final BW was not significantly different among the supplemented goats.

Table 5.2 Effect of supplementation with L. *leucocephala* and M. *oleifera* on growth performance of indigenous goats

Trait	Treatments							SEM*	p-value
	Control	LL_{50}	LL_{75}	LL_{100}	MO_{40}	MO_{60}	MO_{80}		
Initial BW (kg)									
Bucks	17.4	17.9	21.3	21.2	21.3	21.2	22.2	0.560	0.162
Does	16.3	14.9	14.2	14.3	14.3	14.3	14.9	0.491	0.956
Final BW (kg)♣									
Bucks	24.2^{b}	31.8^{ab}	35.8^{a}	34.9^{a}	31.3^{ab}	36.0^{a}	34.1^{a}	1.221	0.001
Does	21.3	22.5	25.4	24.2	21.6	24.9	22.6	0.594	0.461
ADG (g/ head/day)									
Bucks	6.9^{b}	21.9^{ab}	30.2^{a}	28.6^{a}	21.4^{ab}	30.7^{a}	27.1^{a}	1.747	0.001
Does	10.0	15.1	21.9	19.4	14.2	20.7	14.9	1.521	0.437

♣Adjusted body weight, *SEM - Standard error of mean, $^{a-b}$Means in a row without a common superscript letter differ ($p < 0.05$)

Supplementary diet was only provided during the dry season. Results of the average daily weight gain (g/head/day) of goats fed *L. leucocephala* or *M. oleifera* leaf meals in two consecutive dry seasons are presented in Table 5.3. Generally, supplementation of goats with either *L. leucocephala* or *M. oleifera* leaves, irrespective of level, had a significant effect ($p < 0.01$) on weight gain. In year 2, all goats lost weight during the dry season, but it was significantly lower in supplemented goats compared to control goats. In the same year, the ADG did not differ significantly ($p > 0.05$) between goats supplemented with *L. leucocephala* and *M. oleifera* leaf meals.

Within *L. leucocephala* supplemented goats during the first dry season of the study (year 1), a linear increasing of ADG was observed with increasing levels of supplementation with *L. leucocephala*, though increasing from 75 g to 100 g did not increase the ADG significantly. In contrast, during the last dry season of the study (year 2), increasing levels of supplementation with *L. leucocephala* had no significant effect on ADG, though a quadratic trend was observed. On the other hand, during the first dry season, supplementation with *M. oleifera* at 60 g significantly increased the ADG compared to 40 g supplementation, while increasing from 60 g to 80 g did not resulted in benefit as the goats lost on average 5.69 g/head/day. A similar trend on ADG, though not significant, was observed during the second dry season with increasing levels of *M. oleifera* supplementation.

Table 5.3 Average daily weight gain (g/head/day) of goats fed diets contained leaves of *L. leucocephala* (LL) or *M. oleifera* (MO) in two consecutive dry seasons.

Diet	Season			
	Dry 1	**Rainy 1**	**Dry 2**	**Rainy 2**
Co	-20.74	10.06	-36.11	2.60
LL_{50}	-6.25	9.54	-7.85	1.86
LL_{75}	10.42	10.00	-3.06	0.93
LL_{100}	2.22	10.58	-6.46	2.31
MO_{40}	-4.72	10.73	-7.92	1.90
MO_{60}	13.33	10.93	-4.03	2.29
MO_{80}	-5.69	10.14	-7.08	2.36
SEM	2.377	0.263	1.737	0.248
Contrasts				
A	<.010	0.773	<.001	0.417
B	0.031	0.303	0.282	0.630
C	0.264	0.170	0.754	0.649
D	0.280	0.727	0.444	0.979
E	0.020	0.470	0.382	0.299
F	0.897	0.891	0.851	0.128
G	0.014	0.558	0.491	0.621

Co - Control; LL_{50} - Grazing + 50 g of *L. leucacephala*; LL_{75} - Grazing + 75 g of *L. leucacephala*; LL_{100} - Grazing + 100 g of *L. leucacephala*; MO_{40} - Grazing + 40 g of *M. oleifera*; MO_{60} - Grazing + 60 g of *M. oleifera*; MO_{80} - Grazing + 80 g of *M. oleifera*; SEM - standard error of the mean; A - control vs pooled Leucaena and Moringa treatments; B - LL_{50} compared to LL_{75}; C - LL_{50} compared to LL_{100}; D - LL_{75} compared to LL_{100}; E - MO_{40} compared to MO_{60}; F - MO_{40} compared to MO_{80}; G - MO_{60} compared to MO_{80}

To investigate if goats regardless of the season had different growth performance throughout the study period, body weights along the experimental period were compared among treatments (Figure 5.1).

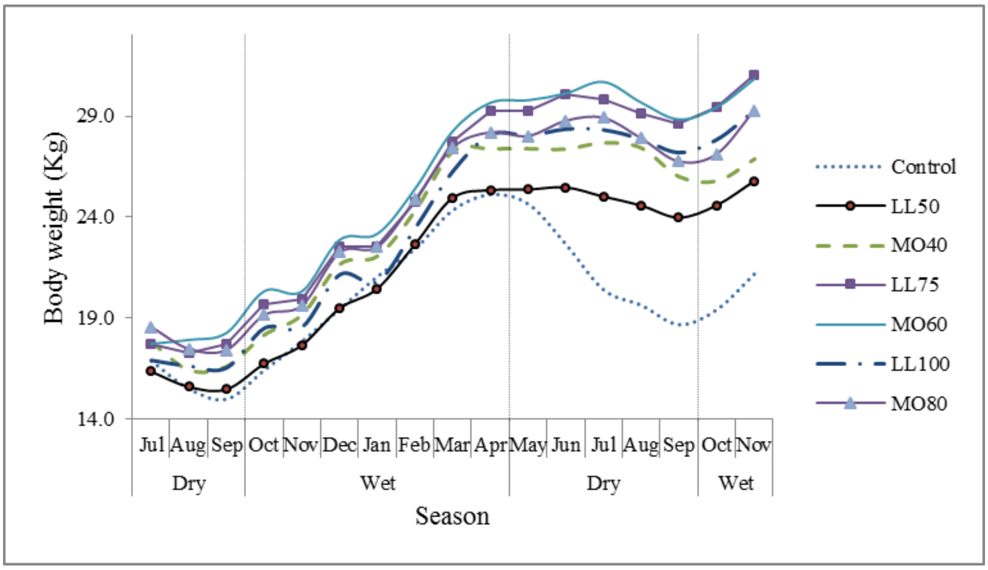

Figure 5.1 Body weight (kg) of goats fed diets contained leaves of *L. leucocephala* (LL) and *M. oleifera* (MO) in two consecutive dry seasons (the year 2015 to 2016)

There was a tendency toward heavier weights when goats were supplemented with either *L. leucocephala or M. oleifera* compared to control goats. Between supplemented groups, goats fed 60 g *M. oleifera* and 75 g *L. leucocephala* leaf meals had heavier weights compared to goats fed other supplement levels, but there were no significant differences on weight gains resulting from both diets. Control goats always showed the lowest weight gain compared to supplemented goats, though no significant effects of diets on weight gains were observed during the rainy season. The goats in the control group didn't show compensatory growth during the rainy season as the weight gain level during the rainy season was not significantly different from the rest of the treatment groups.

Reproductive performance and growth performance of kids

The results of some reproductive traits of does and growth performance of newly born kids are presented in Table 5.4. All does conceived during the experimental period, and the birth rate of supplemented goats (100%) was higher compared to control goats (75%). The twinning rate ranged from 25 to 75% in does supplemented with *L. leucocephala* or *M. oleifera* leaves. Live body weights at birth and weaning weight were not significantly ($p > 0.05$) affected by the type of supplement. However, increasing levels of supplementary diets irrespective of source had a linear effect ($p < 0.01$) on the weight of kids before weaning. Birth type and pre-weaning survival rate of the kids varied among supplementation levels. Goats fed higher level of supplement, except for LL_{100} group, had higher rates of twin births and lower pre-weaning survival rates of the kids compared to other levels of supplementation. The pre-weaning survival rate of the kids was higher in supplemented goats when compared to control goats, though 71.4% of the kids died from the LL_{75} group.

Table 5.4 Effect of diet on some reproductive traits and growth performance of goat kids

Diet	Birth rate (%)	Age at first kidding (years)	Litter size	Twinning rate (%)	Survival rate (%)	Birth weight (kg)	Weaning weight (kg)
Co	0.75	2.30±0.10	1.00±0.00	0.0	50.0	1.60±0.70	7.05±0.05
LL_{50}	100	2.15±0.10	0.75±0.50	0.0	75.0	2.23±0.13	9.30±0.15
LL_{75}	100	2.17±0.08	1.75±0.50	75.0	28.6	2.09±0.16	10.15±0.35
LL_{100}	100	2.13±0.09	1.00±0.00	0.0	75.0	2.00±0.08	9.37±0.35
MO_{40}	100	2.10±0.12	1.00±0.00	0.0	100	2.33±0.15	8.65±0.88
MO_{60}	100	2.24±0.09	1.25±0.50	25.0	80.0	2.14±0.14	9.13±0.43
MO_{80}	100	2.10±0.14	1.25±0.50	25.0	60.0	2.12±0.20	9.53±0.64

Discussion

The chemical composition of *L. leucocephala* and *M. oleifera* leaves used in this experiment have shown similar values to those reported in other studies (Gopalakrishnan et al., 2016). Concerning dried *L. lecocephala* leaves in term of ME, CP and P, the values were within the range reported by Ocran (1994) and Ndemanisho (1996), while ME, CP and Ca in dried *M. oleifera* leaves were similar to those values reported by Ben Salem and Makkar (2009) and Gopalakrishnan et al. (2016).

The positive effect of supplementation with either *L. leucocephala* or *M. oleifera* on growth performance observed in this study was due to the supply of high-quality energy and protein from these feed sources, compared to natural pasture which showed deficiency during the dry season. This result is corroborated by findings of Garcia et al. (1996), Muamba et al. (2014), Hassan et al. (2015), Moyo et al. (2016) and Damor et al. (2017) in goats supplemented with

L. leucocephala and *M. oleifera* during the dry season. Also, Faftine and Zanetti (2010) reported that the low productivity observed in goats fed natural pasture could have resulted from the low efficiency of utilization of fibrous feeds due to the low content of nitrogen, minerals and vitamins and high levels of lignin during the dry season. Moreover, Payne (1990) reported that forage species, in the tropics and sub-tropics, mature and became fibrous rapidly, resulting in poor quality forage. However, the non-significant differences on growth between the control and other treatment groups observed during the rainy season may probably be due to reduced feed intake of the supplemented goats. Similarly, Toukourou and Peters (1999) who studied the impact of feed restriction on the growth performance of goat kids found no difference in body weight gain among the restricted and control groups. Generally, animals are able to grow rapidly and recover body weights after periods of restrictions, and this ability varies according to several factors, such as species, breed, adaptability to harsh conditions, the nature and severity as well as the duration of feed restriction (Yagoub and Babiker, 2009; Onder et al., 2015).

Leucaena leucocephala is considered rich in nutrients with the potential to sustain microbial growth and subsequently allowing higher animal performance (Aletor and Omodara, 1994). However, in the present study, a quadratic effect on weight gain was observed with increasing levels of supplementation, suggesting that beyond certain levels, *L. leucocephala* supplementation may lower the growth performance of goats, probably as result of the presence of limiting factors. Anti-nutritional compounds have been identified in fodder trees (Simbaya, 2002), and among them, tannins and mimosine are present in *L. leucocephala* (Simon, 2012; Adedeji et al., 2013). These compounds depending upon the situation can have beneficial or deleterious effects on animals consuming them (Kumar, 1992). The detrimental effect of anti-nutritional factors in ruminants may range from reduced animal performance to neurological problems and death of the animal (D'Mello, 1992; Aemiro *et al*., 2004; Assefa, 2007; Sen and Onder, 2016b). Several studies have associated the consumption of *L. leucocephala* leaves with lower growth performance in ruminants by limiting nutrient utilisation of ingested feed material (Kumar, 1992; Leng, 1997). However, other studies have reported that diets of moderate to high levels of *L. leucocephala* could be fed to goats without adverse effects on weight gain, as goats were capable of degrading mimosine, and were very well adapted to increase their productivity rate (Kumar and Ashwani, 1998; Yami et al., 2000).

On the other hand, goats fed *M. oleifera*meal had a relatively higher growth performance compared to goats fed *L. leucocephala* meal. The positive effect resulting from *M. oleifera* supplementation was due to the high protein contents. Several studies (Arivazhagan et al., 2000; Moyo et al., 2012; Aboh et al., 2012; Asaolu et al., 2012; Dougnon et al., 2012; Moyo et al., 2016) have reported improvements in growth performance of goats fed diets containing *M. oleifera* leaves. Increasing levels of *M. oleifera* resulted in increased weight gain, though a decrease was observed between 60 g and 80 g supplementation levels, suggesting that a higher beneficial effect was achieved at 60 g supplementation level. Similarly, Bebeker and Abdalbagi (2015) fed goats with three different levels of *M. oleifera* leaves and observed that moderate levels of supplementation resulted in rapid growth performance and could sustain and improve livestock productivity.

Concerning reproductive performance, the higher birth rate observed in goats fed *L. leucocephala,* or *M. oleifera* leaf meals may have resulted from the use of these supplements in animal feed. Supplementary feed rich in energy and protein has a significant positive effect on reproduction in general and ovulation rate in particular (Blache et al., 2008). Previous studies reported increased ovulation rates (Rhind, 1992; Akingbade, 2002) and the incidence of twins (Isaacs et al., 1991; Rhind, 1992) in does feed high protein diets.

Birth weight and weaning weight did not vary significantly among treatments, but kids born from supplemented does had relatively heavier weights compared to those from the control group. Heavier birth weight and weaning weight of kids may have resulted from heavier weights of does at kidding and milking phase, therefore reflecting a positive effect of supplementation. Similar results were observed in other studies conducted for goats under different production systems (Soundararajan et al., 2006; Bushara and Abu Nikhaila, 2011). In contrast, the lower birth weight and weaning weight observed in the control group may be due to the effect of poor quality feeding during the dry season. According to Deminicis et al. (2009), insufficient energy supply is considered to be the primary obstacle in the production of small ruminants, resulting in reduced growth and reproductive performances.

While the high twinning rate observed in goats fed 75 g of *L. leucocephala* leaf meal seems to be due to the positive effect of supplementation, the survival rate of kids was the opposite. This may be indicative of either lower milk produced by does for offspring or a consequence of lighter birth weights of twins, which may contribute to reduced resistance to adverse conditions, such as climate. The lower survival rate observed is in agreement with the results presented by Akingbade et al. (2001) in South Africa, Peacock (1982) in Kenya and Mackinnon and Rocha (1985) in Mozambique, where individual twin goats had a higher mortality rate. Also, *L. leucocephala* leaves have some compounds that act as limiting factors (Ben Salem et al., 2001), affecting the reproductive tract either by their toxicity or by interference in the reproductive control mechanisms, which may result in weak offspring (Kumar, 1992; Leng, 1997).

However, offspring born to goats feed *M. oleifera* leaves had high survival rates. This result may have been influenced by the presence of compounds with therapeutic properties in *M. oleifera* leaves (Bebeker and Abdalbagi, 2015), in addition to the positive effects of supplementation on the does. Similar results were also reported by Qwele et al. (2013) who showed that consumption of a diet supplemented with *M. oleifera* could be a useful source to protect the animals from oxidative stress-induced diseases.

Age at first kidding was not affected by the supplementation with either *L. leucocephala* or *M. oleifera* and ranged between 780 to 690 days. Similar results were reported by Wilson et al. (1989) who found age at first kidding of 693 ± 36.3 days in Mozambique goats. Also, Mackinnon and Rocha (1895) on their study with indigenous goats in Mozambique showed similar results with an average age at first kidding of 738 days.

Conclusion

Supplementation with *L. leucocephala* and *M. oleifera* leaves during the dry season had a positive effect on the growth rate and reproductive performance of goats. Moderate levels of supplements (LL_{75} and MO_{60}) yielded better results and can be used to overcome shortages of good quality feeds. Therefore, *L. leucocephala* and *M. oleifera* represent a good alternative to commercial supplements that can be used by smallholder farmers for feeding goats during periods of feed shortage.

Conflict of Interest

The authors declare that there is no conflict of interest.

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CHAPTER 6

CONCLUSIONS, RECOMMENDATIONS AND CRITICAL REVIEW

Conclusions

Goat production in rural Mozambique is comprised of indigenous goats grazing natural pasture throughout the year. The description of smallholder goat production systems in two resource-poor districts of Mozambique, namely Namaacha and Moamba, indicated that goats were raised under extensive systems. Although the goats are hardy and well adapted to local conditions, this study indicated that their production in Mozambique is limited by poor nutrition, a lack of management and a high prevalence of diseases and parasites. In addition, reviewing of available literature indicated that tethering was a common management practice in the study area that often limited adequate dry matter and nutrient intake of the goats during the dry season.

Generally, during the dry season, the natural fodder was scarce and was poor in quality, which in turn resulted in low intake of energy, protein and phosphorus. This did not meet the energy and protein requirements of small ruminants for maintenance and other functions. Daily energy and crude protein intake of eight key species (namely *Sclerocarya birrea, Spirostachys africana, Dichrostachys cinerea, Flueggea virosa, Acacia nigrescens, Acacia nilotica, Panicum maximum and Morus alba*) that were consumed by the goats in the Changalane district were able to provide adequate energy and protein levels to support maintenance and growth requirements of the goats during the rainy season, but not during the dry season. In contrast, the daily intake of calcium and phosphorus did not show significant seasonal variations and were always below the requirements for maintenance of a 20 kg bodyweight goat during the dry season and a pregnant goat during both seasons. In general the Ca concentration was sufficient throughout the year for both maintenace and reprodution only the P was insufficient.

Furthermore, supplementation with *L. leucacepha* and *M. oleifera* leaves during the dry season had a positive effect on the growth rate and reproductive performance of goats. Moderate levels of supplementation (LL_{75} and MO_{60}) were found to be optimal and these level can be used to overcome shortages of major nutrients during the dry season. Therefore, *L. leucacepha* and *M. oleifera* can be used a*s* supplements to fill the feed gap for goats during periods of feed shortage in Southern Mozambique regions.

Recommendations

Goats are the preferred livestock species in dry areas, due to their ability to convert poor quality natural pastures into protein for human consumption (Ben Salem and Makkar, 2009). They are also one of the most suitable ruminants in drought conditions due to their physiological adaptation to harsh environments (Mirkena *et al.*, 2010; Visser, 2017). Their production potential is, however, limited by a severe scarcity of good quality natural pasture and essential nutrients during the dry season, poor management and the high prevalence of diseases and parasites (Nsereko *et al.*, 2015; Mataveia *et al.*, 2018; Onzima *et al.*, 2018). These limitations should be considered during the design of a management program.

To ensure more collaboration from the smallholders, researchers should explain to the participants how survey results will be used to understand the constraints and opportunities in order to improve productivity within smallholders' system. They then need to promote the use of these results in the design and implementation of programs that address aspects raised by smallholders, including training and technology transfer on relevant issues. There is a need for appropriate intervention strategies to improve goat production, through education of farmers on good husbandry practices, such as improved breeding and feeding practices as well as disease control strategies. The baseline information provided in this study will contribute to the development of coordinated and comprehensive goat production improvement programs and ultimately improve goat productivity and the livelihood of rural farmers.

Regarding the availability and seasonal variability in the nutritional values of vegetation, there is a need to educate communities to avoid overgrazing and uncontrolled fires as well as training on how to build "fire breaks" in order to separate grazing and cropland during the dry season. This should be done to ensure that during this period, there is still standing hay available for animal feed, and thus to alleviate the food shortage during this period.

The need to supplement goats with energy, protein and phosphorus mainly during the dry season to increase reproductive and production performances was clearly demonstrated. Both *Leucaena leucocephala* and *Moringa oleifera* are easy to plant and are resistant to droughts. Levels of supplementation must be indicated to smallholders in a way that is possible to implement practically as the level indicated in the current study might hold practical challenges as these goat keepers don't have facilities such as scales.

I recommend that tree fodder be conserved because they are abundant locally in the villages and are a cheap source of protein for small farmers for feeding their animals. It is possible to harvest the mature fodder (*Leucaena leucoceplaha* and *Moringa oleifera*) manually during the rainy season (when they are more readily available). The leaves can be air-dried in shade by spreading them on clean plastic sheets and turning them several times for 72 h, after which they can be stored in sisal bags until use in the dry season (when there is shortage of them). Besides these two species the other naturally occurring species which can be used by farmers as protein supplements are *Flueggea virosa and Morus alba.*

Critical review

The survey performed in rural areas had some limitations. Firstly, some resistance from goat keepers regarding the completion of surveys was noticed, partly because respondents generally feel that they do not get anything back from the studies. Goat keepers showed a common mistrust of institutions responsible for research. Thus, only a small number of goat keepers were willing to participate in the current study. Regardless of these challenges, the information provided in this study provides baseline information on smallholder management systems in Mozambique and will contribute to the development of coordinated and comprehensive improvement programs. The limitation related to the survey can be overcome by increasing the number of districts to gather the information (increase the replicates), as well as, providing technical veterinary assistance (deworming and infectious disease treatment) to goats which can result in good relation between research institutions and community.

The investigation of seasonal variation in the composition of natural fodder in Changalane was the first study in Mozambique that reported the nutrient composition of a variety of natural fodder vegetation species preferred by goats throughout a year period. To improve this study, it would be useful to have replications of the study carried out over a few years, to allow comparison of the results. The study could also include improved monitoring techniques of goats browsing on the native pastures and measurement of parameters such as pasture growth rate, feed intake and average daily gain, which can be used to evaluate the productive performance of goats.

Furthermore, this study did not estimate or report the bite rates of the various vegetation. The collection of this data was started at the beginning of the experiment, but due to the lack of funds allocated for this specific test, its completion was not possible. The methodology to estimate the bite rate is quite complex and labour intensive, i.e requires the individual observation of at least three goats for five consecutive days each month. This could be done by a researcher with two technical assistants, who would collect the frequency of bites, species preferences and subsequent identification of the most frequently consumed shrubs and grasses. As this is both labour- and time-intensive, the available resources could not accommodate these observations. A future study should be performed in order to calculate the pasture productivity using the 1m^2 quadrant approach; to estimate dry matter intake through integration of total fecal collection with internal and external marker as well as using video camera Closed-Circuit TV (CCTV) and other cameras to monitor the grazing behaviour of the goat and accurately identify plants selected for a bite.

The approach to use the mebabolisable energy (ME) values were derived in this study has some limitation since it is almost impossible to predict the balance of nutrients reaching the sites of metabolism and at least needs the knowledge of rumen Volatile Fatty Acids (VFA) patterns in the rumen to determine the total mebabolisable energy, rumen ammonia values and potential rumen escape of the diet protein. Some alternatives are the use of acid insoluble ash or chromic oxide as markers to estimate the ME and nitrogen retention of diets (Scott and Hall, 1997).

The assessment made of the nutritive value of natural fodder in Changalane showed a decrease of the quality of natural fodder in the dry season and a need to supplement goats with energy, protein and phosphorus for maintenance, growth and reproductive functions during the dry season. To ensure better year-round nutrition for the animals, improved natural pasture management practices should be introduced. Smallholders should further be trained to make use of alternative, low-cost food supplementation, focusing on locally available trees and shrubs.

Regarding the study that evaluated the impact of supplementation of *Leucaena leucacepha* and *Moringa oleifera* tree fodder on the production performance of indigenous goats, several improvements could be considered in future studies. A relatively small number of females per treatment was used over the two kidding seasons. The researcher had to buy and allocate the animals to smallholders, and limited funds were available for animal acquisition. Care was taken to obtain statistically significant results, but larger sample sizes would contribute to a more robust experiment. Supplementation levels were calculated based on the daily intake of

200g of natural pasture (dry matter) assuming the low availability of natural pasture during the dry season, due to the desire to simulate farmers condition which often encounters uncontrolled fires and the practice of short grazing periods of the animals common in the area (see Appendix C for more details on the calculation of the required supplementation).

Leucaena leucocephala (LL) is mostly used as a supplement for animals in Mozambique. *Moringa oleifera* (MO) is widespread throughout the country but is not commonly used as a supplement for ruminants, even though previous studies have highlighted its benefits. The current study is the first to investigate the supplementation of indigenous goats with MO in Mozambique. More research and the dissemination of knowledge regarding available fodder trees as supplements in Mozambique is necessary. The use of fodder trees, as well as other low-cost supplements, is particularly important since goat production is widespread within the smallholder sector. This segment of society is commonly resource-poor and unable to invest in expensive interventions such as commercial supplements and medicines to improve goat production.

Although,the secondary metabolites in LL was not the focus of this study, they deserve some mention. It has been showed that LL could negatively affect small ruminants, while some researchers observed an advantage of goats compared to other ruminants when consuming tannin-rich plants. This relates to the goats' superior capacity to neutralize the negative effect of tannins on palatability and digestibility. For example, trypsin inhibitors which are anti-nutritional factors for monogastric animals do not impose adverse effects in ruminants because they are degraded in the rumen. The presence of low levels of tannins may enhance feed nutritive value by protecting proteins from ruminal degradation and making it available for lower tract digestion (Garcia *et al*., 1996; Silanikove *et al.*, 1996; Garcia *et al.*, 2011). Fasae *et al* (2011) recommends that LL should be fed dried so as to reduce the content of the anti-nutritional factors namely mimosine and tannin.

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APPENDICES

Appendix A: Consent form

CONSENT FOR PARTICIPATION IN A RESEARCH INTERVIEW

Research Title: The use of *Moringa oleifera* and *Leucaena leucocephala* tree leaves to improve smallholder goat production in Mozambique

Name of Researcher: Gracinda Andre Mataveia – PhD student

Student number -23427893

University of Pretoria

South Africa

I volunteer to participate in a research project conducted by Gracinda Andre Mataveia from the University of Eduardo Mondlane and PhD Student at the University of Pretoria. I understand that the project is designed to collect information about goats production system, socio-economic factors, general management and restrictions encountered for goats production. I will be one of approximately 100 people being interviewed for the current research.

My participation in the present project is voluntary and I am free to refuse to participate and I am free to withdraw from the interview at any time. My refusal to participate or withdrawal of consent will not affect my relationship with the University Centre of Changalane of Eduardo Mondlane University and the University of Pretoria.

I understand that the data collected from my participation will be used for the purpose of thesis and journal publication and I consent for it to be used in that mode.

I have read and understood the explanation provided to me. I have also had all my questions regarding the research answered to my satisfaction, and I voluntarily agree to collaborate in this project.

Name ________________________

Signed_______________________

Data ___/____/____

Appendix B: Questionnaire

Goat production in Mozambique –Questionnaire

Goat production in Moamba, Michangulene and Mahelane villages has great potential for food security and income generation for resource-poor farmers. In order to design sustainable production improvement programs, the importance of goats to smallholder farmers and their specific production environment need to be evaluated and clearly understood. The success of any genetic/production improvement and conservation program depends upon the action of livestock keepers who own, utilise and adopt breeds and adapt them to their needs. Therefore, the aim of this survey is to obtain information regarding the social-economic importance of goat's production and fodder tree supplementation on villages in Mozambique.

DEMOGRAPHIC INFORMATION

Name________________________ Surname______________________

Address_______________________ Location

Village_______________________ Districts_____________________

Region_______________________ Farm name____________________

HOUSEHOLD STRUCTURE

Land ownership a) own b) lease c) other (Specify) _____________________

Head of household a) Male b) Female

Position in the household a) head of household b) spouse c) son d) daughter

e) Brother f) sister g) other (specify) __________________

Age a) ⩽ 30 b) 31 -45 c) 46 -60 d) ⩾ 61

Marital Status a) Married b) Single c) Marital union d) Widow

Level of education a) Primary b) Secondary c) Tertiary d) None

Number of people living in the household

Male ☐ Female ☐ Children < 15 years ☐

Is livestock major activity a) Yes b) No

Source of income (Please tick where applicable and rank according to importance)

Activity	Tick	Rank 1,2,3
Salary/wages		
Crops		
Livestock		
products		
Home industries		
Other (Specify)		

Livestock Kept (Write total number for each species kept and rank according to importance)

Livestock	Number	Rank (1,2,3)
Cattle		

Goats
Sheep
Chicken*
Pigs
Donkeys
Other

*adults birds only

Livestock production category

Meat	Milk	Dual purpose
Cattle	Cattle	Cattle
Sheep	Sheep	Sheep
Goat	Goat	Goat

Trend in livestock population over 2 year and land holding status; please circle where appropriate

Cattle	**Sheep**	**Goat**	**Land holding status**
a) Increase	a) Increase	a) Increase	a) Increase
b) Decrease	b) Decrease	b) Decrease	b) Decrease
c) No change	c) No change	c) No change	c) No change

Reasons for decline in land holding a) drought b) increase in population c) Diseases d) lack of funds e) Spoil f) no idea g) other___________________

Reasons for increase in land holding a) Buy land e) no idea
f) other___________________

Reasons for increase the goats
a) Births of animals received from the project b) Births of twins c) no idea

The head of household have access to the Use Law and Land Utilisation (DUAT)
a) Yes b) No

Flock Management

Do goats run with other livestock: a) Yes b) No

GOAT PRODUCTION

Type of production system a) Extensive/ pastoral b) free-range/backyard c) other ______________________________

Purpose of keeping goats (place the "X" and Rank, 1 for primary purpose, 2 for secondary, 3 for third purpose)

Purpose	"X"	Rank
Meat		
Milk		
Skin		
Cash from Sales		
Ceremonies		
Breeding		
Insurance/emergency		
Cultural rites		
Investment		
Manure		

Members of household responsible for goat activities (place the "X" *where necessary*)

Activity	Male adult	Female adult	Boys (<15)	Girls (<15)	Hired Labour
Feeding					
Milking					
Breeding decisions					
Slaughtering					
Selling					
Purchasing					
Animal Health					
Other					

Feeding

Source of feeding (place the "X")

Source of feeding	Dry season (place the "X")	Wet season (place the "X")	Feed supplement	Dry season (place the "X")	Wet season (place the "X")
Natural Pasture			*Leucaena leucocephala*		
Hay			*Moringa Oleifera*		
Crop residue			crop residue/roughage		
Tethered			Concentrate		
Yard			Minerals (salts)/vitamin		
Other_____________			None		
			Other		

Watering

How animals are watered ("X")	**Dry season**	**Dry season**
Animals go to water		
Water is fetched		
Both		
Source of water ("X")	**Dry season**	**Dry season**
Borehole		
River		
Pond		
Rain water		
Tap water		
Other		
Distance towatering point ("X")	**Dry season**	**Dry season**
<1km		
1-5 km		
6-10 km		
>10 km		

Frequency of watering	Dry season	Dry season
Adlibitum		
Once a day		
Twice a day		
Every other day		
Once in 3 days		
Other		
Water quality	**Dry season**	**Dry season**
Good/clear		
Salty		
Smelly		
Other		

Management of feeding (place the "X")

	Dry season	Wet season
Grazing and browsing on Communal Natural Pasture		
Herded		
Tethered		
Other_____________		

Housing

Method of housing (place the "X" appropriately)

Method	Dry season		Wet season	
	Day	Night	Day	Night
Kraals				
Stall/shed				
Yard				
None				
Other___________				

Wire

Mud

Materials used for housing (X")

Bricks

Untreated wood/bush

Treated wood

Iron sheets

Other__________

Form of housing (place the “X” when present)

Roofed

Solid wall

Concrete floor

Wooden floor

Earth floor

Other___________

Herd Health

Access to veterinary services a) Government vet b) Private vet c) veterinary drug supplier d) Extension service e) None f) other ____

Common Diseases or symptoms seen (Rank according to most common)

Treatment of Diseases (If known)

Frequency occurrence of diseases

a) dry season b) wet season c) all year round

a) dry season b) wet season c) all year round

Vaccinations and preventative medicines given a) Yes b) No

Vaccinations and preventative medicines given a) Yes b) No

If yes fill the table below with “X” appropriately

Name Diseases/symptoms	Done routinely	Done when need

External parasites control a) Yes b) No (*If yes fill the table below*)

Method	XX"	Done routinely		Done when need		If done routinely specify how often	
		Dry season	Wet season	Dry Season	Wet season	Dry season	Wet season
Spray							
Pour-on							
Dip							
Hand-dressing							
Injectable							
Traditional							
Other______							

Specify traditional

Endoparasites control a) Yes b) No (*If yes complete the table below*)

Method	Tick	Done routinely		Done when need		If done routinely specify how often	
		Dry season	Wet season	Dry Season	Wet season	Dry season	Wet season
Drench							
Injectable							
Other							

<u>Castration</u>

Do you castrate a) Yes b) No

If yes, the age of castration a) 0-3months b) 3-6 months c) 6-12months d) 12-24months

Method of castration a) knife b) rubber ring c) burdizzo

Reasons for castration a) improve meat quality b) improve temperament c) control breeding d) other __________________

Marketing and culling

Do you cull a) Yes b) No (*If yes complete the table below)*

Reasons	Male	Rank	Female	Rank
Temperament				
Diseases				
Old age				
Deformities				
Poor Performance				
Poor fertility				
Body size				
Body conformation				
Other				

Do you sell a) Yes b) No

How often do you sell? ☐

Where do you sell a) Traders b) Consumers c) Farmers e) auctions e) abattoirs f) other.....

When do you sell? a) Holidays b) Ceremonies c) during drought d) shortage of food commodities e) other__________________

Sex of animals sold a) entire males b) castrates c) females d) mixed

Age of animals sold a)⩽ 6 months b) 7-12 months c)12-18 months d) 18-24 months e) 24-36 months f)>36 months

Reasons for selling ____

Breeding

Mating a) uncontrolled b) group mating c) hand mating d) other__________

Source of breeding buck a) Borrowed b) hired c) bought

d) Own herd e) Communal area buck f) other__________________________

Type of buck (breed name, if known) ____

Reasons for choice of buck tick and rank (1, 2, 3)

	"X"	R 1,2,3
Body conformation/shape		
Body size		
Colour		
Performance		
Availability (no choice)		
Other_________________		

How long do you use the buck for breeding? a) 1-2years b) 2-4 years c) ⩾5 years

Breed of goat kept a) indigenous b) pure exotic c) indigenous x exotic crosses

d) exotic crosses

Flock structure of goats kept; circle where applicable number kept

Kids (⩽ 4months)	Weaners (5-12months)	Adults (>12months)
a) ⩽ 10	a) ⩽ 10	a) ⩽ 10
b) 10 – 20	b) 10 – 20	b) 10 – 20
c) 21 – 40	c) 21 – 40	c) 21 – 40
d) 41 -50	d) 41 -50	d) 41 -50
e) >50	e) >50	e) >50

Origin of goats kept a) bought b) inherited c) Gifts d) acquired through goat scheme e) exchanged f) other____

Quality of your animals (farmers perception) rate them according to (Poor, average & good)

Trait	Male			Female		
	Poor	Aver	Good	Poor	Aver	Good
Growth rate						
Body size						
Meat						
Milk						
Prolificacy						
Disease tolerant						
Drought tolerant						
Heat tolerant						
Temperament						
Body shape						
Colour						
Fertility						
Other_______						

Record keeping a) Yes b) No

What kind of records do you keep? ________________

Reproductive performance

Age of male puberty a) 6-12 months b) 12- 18 months c) 18- 24 months

Age of female puberty a) 6-12 months b) 12- 18 months c) 18- 24 months

Age at first service a) 6-12 months b) 12- 18 months c) 18- 24 months

Age at first kidding a) 6-12 months b) 12- 18 months c) 18- 24 months

Kidding interval a) 6-8 months b) 8-12 months c) 18- 24 months

Average reproductive life span a) 3-5 years b) 6-8 years c) 9-11 years d) ⩾ 12

Twinning rate a) ⩾ 50% b) 60%- 70% c) 70%-90%

Weaning Practices a) Natural b) artificial c) other______________

Weaning age a) 2-4 months b) 4-6 months c) 6-8 months d) 8-12 months

Major constraints

List the constraints encountered according to their occurrence:

____

____

ANIMAL AND SAMPLING INFORMATION

Breed a) Indigenous b) exotic c) crossbred

Dentition a) 1- one year b) 2- 18 months c) 3-2years d) 4- 2,5 to 3 years e) 5- 3,5-4 years

Age a) ⩽ 1year b) 1-2years c) 2-3 years d) 3-4years e) ⩾5 years

Sex a) entire male b) female c) castrate

Phenotypic characteristics

Trait	**Measurement**
BW	
CS	
HG	
Colour	
Horned	Yes/ No
Beard	Yes/ No

BW= body weight; CS= Condition Score

HG= heart girth;

Type of biological sample a) Blood b) Hair

Area collected____________________________________

Date of collection________________________________

Name of collector________________________________

Appendix C: Details of calculation of the required supplementation

Assuming low availability of natural pasture during dry season, due to the uncontrolled fire, low quality, availability of natural pasture, and also poor grazing time management (5 hours) instead of recommended 8 hours we estimated a daily intake of 200 gram natural pasture (dry matter), with a nutrient daily intake of:

- Crude protein: 23.66 g per 200 g DM
- Calcium: 4.37 g per 200 g DM
- Phosphor: 0.39 g per 200 g DM

Table 1: Estimated nutrient daily intake of crude protein, calcium and phosphorus

	CP (g)	**Ca (g)**	**P (g)**
Daily Intake (g/200g DM)	23.66	4.37	0.39
Daily Goat Requirement	36	1.2	0.8
Nutrient Deficit (g)	-12.34	-	-0.41

The deficit in Crude Protein and Phosphor will be covered supplementing animals with *Leucaena leucocephala* and *Moringa oleifera* whose contents in Crude Protein and Phosphorus are presented in table 2.

Table 2: Content nutrient in different ingredients in DM

	CP (%)	**Ca (%)**	**P (%)**
Nat Pasture* (July)	11.83	2.19	0.2
Leucaena leucocephala	23.70	3.26	0.15
Moringa oleifera	28.80	2.21	0.24

*Grass (*Setaria verticallata, Botriochloa Isculpta, Heteropogon Contortus, Urochloa Mosambicensis, Panicum Maximum, Aristida spp, Themeda Triamda, Cynodon dactylon and Sorghum halapensis)* and shrubs *(Flueggea Virosa*)

Natural Pasture: Data from base line study; *Leucaena leucocephala* and *Moringa oleifera*:

Data from analysis of *Leucaena leucocephala* and *Moringa oleifera* samples at *UP-Nutrilab*; Maize: Data from Highest (Protein and Phosphor) and Kleyn (2013) (Calcium).

Required amount of l *Leucaena leucocephala* to cover the deficit 12.34 grams of Crude Protein is calculated using Crude Protein content in *Leucaena leucocephala*

$$\text{mass}_{\text{leucaena}} = \frac{12{,}34}{23{,}70} \text{ X } 100 = 52.06 \text{ grams leucaena}$$

Addition of 52.06 grams leucaena contributes for the introduction of

$$\text{Mass}_{\text{phosphor}} = \frac{0{,}15 \times 52{,}06}{100} = 0{,}078 \text{ grams phosphor}$$

Thus reducing phosphor deficit from 0.41 grams to **0.332 grams** (0.41 – 0.078 = 0.332 grams).

Similarly, required amount of moringa to cover the deficit 12.34 grams of Crude Protein is calculated using Crude Protein content in moringa

$$\text{mass}_{\text{moringa}} = \frac{12{,}34}{28{,}80} \text{ X } 100 = 42{,}84 \text{ grams moringa}$$

Addition of 42.84 grams moringa contributes for the introduction of

$$\text{Mass}_{\text{phosphorus}} = \frac{0{,}24 \times 42{,}84}{100} = 0.1028 \text{ grams phosphorus}$$

Thus reducing phosphorus deficit from 0.41 grams to **0.3072 grams** (0.41 – 0.1028 = 0.3072 grams). Phosphorus deficit will be covered by addition of a phosphorous salt in the amount required to cover the 0.332 grams and 0.3072 grams for the *Leucaena leucocephala* and *Moringa oleifera* diet respectively.

These results were then used to calculate the amounts of each ingredient on the basic diet (maintenance) and the diets with an additional amount of 15 and 30% Crude Protein, calculated based on the daily requirement of protein.

Table 3: Resumed data of the mixture and total of supplement to administration per goat /daily

Diet	**Composition**	**Nat Pasture**	**Supplement[1] Maintenance**	**Additional supplement**	**Total Supplement to administration per goat /daily**	**Total**
Leucaena Diet	Maintenance	200 g	52.06 g	---	52.06 g≈ 50g	252.06 g
	Maintenance + 15% Supplement	200 g	52.06 g	22.78 g	74.84 g ≈ 75g	274.84 g
	Maintenance + 30% Supplement	200 g	52.06 g	45.56 g	97.62 g ≈ 100g	297.62 g
Moringa Diet	Maintenance	200 g	42.84 g	---	42.84 g ≈40g	242.84 g
	Maintenance + 15% Supplement	200 g	42.84 g	18.75 g	61.59 g ≈60g	261.59 g
	Maintenance + 30% Supplement	200 g	42.84 g	37.50 g	80.34 g≈ 80g	280.34 g

[1] **Maintenance amount of supplement.**