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FEEDING BEHAVIOUR, PLANT SPECIES SELECTION AND *IN SACCO* RUMINAL DIGESTION IN TSWANA AND BOER GOATS

By

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DECLARATION

I ____, hereby declare that the work contained in this thesis is entirely my own work with the exception of such quotations or references which have been attributed to their authors or sources.

Dated at ______________________________this ________ day of ____________ 2010

Cornelia Kedidimetse Lebopa

"Never underestimate God. He works in mysterious ways.
He changes the times and seasons and gives wisdom to the wise and knowledge to those who have understanding" Daniel 2:21

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DEDICATION

I dedicate this thesis to:

My husband and our kids

My husband, Nicholas for being my pillar of strength, and our sons Thabang and Tumisho, and our daughter, Resegofaditswe. I thank you Darling for your love, support, patience, encouragement and allowing me to pursue my dream while you tirelessly looked after our kids. You were the wind beneath my wings!

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ABBREVIATIONS

ADF	-	acid detergent fibre
ADL	-	acid detergent lignin
BW	-	body weight
CP	-	crude protein
CPD	-	crude protein degradability
DM	-	dry matter
DMD	-	dry matter degradability
DMI	-	dry matter intake
GBD/ha	-	goat browsing day/ha
N	-	nitrogen
NDF	-	neutral detergent fibre

ABSTRACT

The first experiment of this study was aimed at investigating the factors affecting the feeding behaviour and plant species selection of 3 free ranging Tswana (mean weight ± 37 kg) and 3 Boer (mean weight ± 36 kg) goat does in the False Thornveld of the Eastern Cape Province, South Africa. The feeding behaviour and plant species selection was observed and recorded during winter (cold-dry season) and summer (hot-wet season). Observations included the following categories: browsing, grazing and non-feeding activities. Non-feeding activities (NFA) include separate recordings of walking, standing, lying and drinking. Results showed goats spent 21.9 %, 44.65 % and 33.3 % of their day on browsing, grazing and non-feeding activities. Grass was clearly the preferred feed for goats both in the cold-dry season (54 %) and the hot-wet season (76 %) while browse consumption was higher in the cold-dry season (46 %) and lower in the hot-wet season (24 %). Goats spent more time on NFA in the cold-dry season (68.8 %) than the hot-wet season (31.9 %). Though diurnal variations were observed for both breeds and seasons in terms of browsing and non-feeding activities, no diurnal variations were found between the breeds.

Goats selected a wide spectrum of woody-plant species. A total of thirteen woody plant species were encountered and selected by goats in the range. *Scutia myrtina* was the most frequently consumed (29.9 %) woody plant species in the range followed by *Rhus refracta* (16.3 %), *Grewia occidentalis* (14.0 %), *Olea africana* (10.8 %). These four woody-plant species accounted for 71 % of the woody plant selection by goats. Significant differences ($P<0.001$) were found in percentage time spent selecting the different woody-plant species by goats. The frequency of woody-plant species selection was higher in the cold-dry season than the hot-wet season. Woody-plant selection was higher in the morning followed by the afternoon and lower during midday. Percentage time spent by goats selecting woody plant species decreased with advancing period of occupation of a grazing/browsing camp. Browse was the preferred feed when feed availability was high, but when feed availability declined, the goats decreased their frequency of woody-plant selection and more grass was eaten.

The second experiment was aimed at determining and comparing the nutritive value of forages selected by the same free ranging goats. Three (3) Tswana and 3 Boer goats equipped with remote controlled fistula valves were studied. Fistula valve samples were collected for 15 minutes during the day at 6 different times. All extrusa samples were kept on ice in the field and then stored in a

deep freeze prior to drying and milling. Each sample was freeze-dried and hand separated into bush (woody species) and grass components (including forbs). These samples were analysed for nitrogen (N), neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL). The diets selected by the goats differed in CP (cold-dry season: 5.39 % ± 0.15 and hot-wet season 9.48 % ± 0.15; P=0.001), NDF (cold-dry season 48.09 % ± 1.02 and hot-wet season 53.76 % ± 1.02; P=0.001) and ADF (cold-dry season 34.32 % ± 0.72 and hot-wet season 37.50 % ± 0.72) between the seasons, but the ADF content showed no change (cold-dry season 18.01 % ± 0.52 and hot-wet season 19.49 % ± 0.52 P>0.05). Goats selected diets higher in CP, NDF and ADF during hot-wet season compared to cold-dry season. Generally, there were diurnal variations in the NDF (P=0.04), ADF (P=0.02) and ADL (P=0.01) contents of forages selected by goats. Nutrient content of selected diets decreased in quality with advancing period of occupation of a camp. Knowledge of the nutritive value of the diet as selected by these animals is of primary importance in estimating the productivity of any rangeland.

The third experiment was aimed at determining *in sacco* dry matter (DM) and crude protein degradation of woody plant species incubated in the rumen of Tswana and Boer goats. The ruminal degradability of the three most selected woody plant species by goats during the cold-dry season (*G. occodentalis, O. africana* and *S. myrtina*) and the hot-wet season (*A. karroo, R. refracta* and *S. myrtina),* were measured in situ, using *in sacco* digestion techniques. The nylon bag incubation revealed large differences in the rumen degradability of DM of the three woody plant species during both cold-dry season and hot-wet season. Ruminal degradation constants (*a, b* and *a+b* and *c*) varied significantly (P<0.001) between breeds and between goats within a breed. Thus, no breed difference in *in sacco* degradation of DM and CP was found between Tswana and Boer goats. There was a strong positive correlation between DMD, CPD and time of incubation in the rumen. The crude protein content of the woody plant species positively influenced the rumen digestion of dry matter because when CP increased DMD also increased. Both species preference and degradability of plant species are needed to estimate range suitability for browsing animals.

Results from this study will help to develop strategies to optimise range resources for sustainable animal production. In order to improve production, the constraints limiting success should be identified. Tswana goats might be a more favoured breed in semi-arid savannah because of their smaller body size, absolute nutrient requirement and better reproductive performance when compared to Boer goats. However, when forage availability is not a limiting factor, Boer goats might yield better returns for the investment since they are superior in meat production.

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CHAPTER 1

INTRODUCTION

In the arid and semi-arid regions of the world, goats are the cornerstones of livestock production in both commercial and communal sectors. The majority of goats in the world exist on rangelands where seasonal feed shortages and low value of available feed resources are considered the most widespread technical constraints to small-stock production systems (Schlecht *et al*., 2006; Salem & Smith, 2008). These production systems are regarded as essential in many parts of the developing world (Mellado *et al*., 2004; Ouedraogo-Kone *et al*., 2006). The low quality and seasonal nature of forage supply, together with low intake rate by animals and poor digestibility of forage, contribute to the low productivity of goats (Shinde *et al*., 2000; Ngwa *et al*., 2000; Sanon *et al*., 2007). The processes governing digestibility are primarily defined by the forage being fed, whereas those governing intake are functions of the forage and the animal as impacted by its environment (Coleman *et al*., 2003).

The rangelands of Southern Africa support diverse and dynamic ecosystem that sustains wildlife, game and livestock farming (Tefera *et al*., 2008). In South Africa, approximately 80% (68.4 million ha) of land available for agricultural purposes can only be utilised effectively by free ranging herbivores (de Waal, 1990). Although the natural vegetation provides the bulk of the nutrients for domestic livestock and all the nutrients for wild herbivores (Harris *et al*., 1967), its ability to sustain animal production varies substantially according to climate, geography, plant community, bush encroachment and range deterioration (Keskin *et al*., 2005). Knowledge of the feeding behaviour, diet selection and nutritive value of the diets selected by free-ranging goats is of primary importance in estimating the productivity of any rangeland for any particular species of animal (Sanon *et al*., 2007). However, factors that affect the diet selection and food intake rate by goats are poorly understood (Dziba *et al.*, 2003; Torrano & Valderrabáno, 2005).

Grazing goats, therefore, exist in a highly dynamic situation where its productivity is primarily dependent on the net nutrient intake beyond maintenance requirements (Sun *et al*., 2008). Nutrient intake is, in turn, a function of the quantity and quality of the dry matter ingested (Dziba *et al*., 2003) which is regulated by a series of short-term decisions made by the goat such as which plants are selected and how long to search between bites (Gordon, 1995). In previous work (Mogorosi *et al.*, 1996; Raats *et al.*, 1996a; Raats *et al.*, 1996b; Dziba *et al*., 2003), it was found that goats prefer some species to others and that intake rates vary between plant species. Long-term decisions concern the length of time to spend feeding and where to feed (Gordon, 1995). This collection of decision-making factors is defined as the foraging strategy of the animal (Gordon & Illius, 1992). In general, individual grazers tend to focus on the nutrient rich items when resources are abundant, and increase the diversity of plant species in their diet when food availability decreases (Torres & Puig, 2010). Understanding the mechanism by which herbivores interact with forage resources and adjust foraging behaviour, is a driving force behind many research projects (Rogosic *et al*., 2007).

If the most efficient use of the plant and animal resources available in marginal areas is to be made, it is essential to improve our understanding of the foraging strategies of the goats which use these ecosystems (Gordon, 1995; Torrano & Valderrábano, 2005; Sanon *et al*., 2007). For achievement of acceptable levels of goat performance compatible with resource preservation, a deep knowledge of feeding behaviour, diet section, digestive and metabolic processes, nutritive values of feeds and nutrient/energy requirements is needed. Efficient utilization of available resources also requires the provision of data on plant density, forage species and phytomass at any specific site to define its carrying capacity and strategies of feed supplementation according to desired level of production (Lachica & Aguilera, 2003; Sanon *et al*., 2007; Yayota *et al*., 2009).

The reasons for studying the foraging behaviour of goats are to estimate intake and energy budgets; to understand the relationship between resource distribution, sward structure and herbage intake; to explain between-animal variation in intake and performance in relation to animal nutritional status, grazing regime and management practices and to provide answers to questions about the distribution and impact of livestock on the vegetation. Included is the effect of climatic conditions and land use on the relative use of resources by herbivores (Gordon, 1995).

A further reason for measuring the diet composition of range animals (plant species preference, nutrient composition and harvesting rate of different plants) is to rank plant species according to their potential feeding value in different animal production systems. An understanding of diet selection and intake rates by ruminants on rangelands underpins efficient management and profitable animal production (Torrano & Valderrábano, 2005; Sanon *et al*., 2007). This plant value system provides a basis for the assessment of veld condition in relation to both primary and secondary production (Gordon, 1995).

Knowledge of the grazing animal's food habits and forage preference is fundamental to the effective design of grazing systems, the evaluation and prediction of the effects of grazing use on plant communities and formulation of economical supplementation programmes on nutritional deficient ranges (Malecheck & Leinweber, 1971; Lachica & Aguilera, 2003; Sun *et al*., 2008). However, not much is known about the feeding behaviour, plant species selection and digestive efficiency of free ranging Tswana goats or how they compare to Boer goats.

The North West Province is a semi-arid area characterised by low rainfall which results in seasonal shortages and low quality of available feed resources. The majority of farmers in the area obtain their livelihood from goat farming as goats are able to survive under harsh environmental and nutritional conditions. The two most common goat breeds in the North West Province are indigenous Tswana goats and the Boer goats which are kept in communal grazing lands. The feeding behaviour and diet selection of Boer goats is well documented, but not much is available on the Tswana goat, even though many farmers insist that these goats are superior. In order to practice sustainable goat production in the North West Province, farmers must be provided with information about the nutrient requirements of the goats and the available feed resources and their utilization within the animal body. The current study aimed at obtaining such information by conducting research on the feeding behaviour, plant selection and digestion efficiency of these free ranging goats. Tswana and Boer goats being the common breeds in the Province, the study examined both breeds to ascertain if any differences do exist and to improve available knowledge on the feeding behaviour and diet selection. Results of the research will give a clear understanding of factors affecting the feeding behaviour, diet selection, nutrient content and digestibility of forages selected by free ranging goats.

1.1. Objectives

The objectives of the study were to:

1. Compare diurnal changes in feeding behaviour and plant species selection of the Tswana and Boer goats (variation within and between breeds) during the cold-dry season and the hot-wet season;

2. Compare the nutritive values of feeds selected by the Tswana and Boer goat during the cold-dry season and the hot-wet season; and

3. Determine the rate of ruminal degradability of the three most preferred bush species selected by the Tswana and Boer goats during the cold-dry season and the hot-wet season using *in sacco* digestion.

1.2 Hypotheses

1. Indigenous Tswana goats spend more time browsing than the Boer goats, and time spent browsing will be influenced (negatively) by the availability of forage.
2. Indigenous Tswana goats and Boer goats have different diet selection patterns between browse species.
3. Indigenous Tswana goats tend to select more nutritious diets than do the Boer goats.
4. Indigenous Tswana goats are more efficient at digesting fibrous forage than do the Boer goats.

CHAPTER 2

LITERATURE REVIEW

2.1. Origin of goats

Goats were amongst the first animals to be domesticated for the production of meat, milk, skin and fibre (Anbarasu *et al.*, 2004; Webb & Casey, 2010). Originating in Asia before 7500 BC, goats have spread all over the continents and inhibit almost all climatic zones from the arctic circle to the equator. Goats belong to the genus *Capra*, within the tribe *Caprini* of the family *Bovidae*. The world's goat population is today over 750 million (Lu *et al.*, 2010). In 2005, South Africa had a goat population of about 6.4 million (Statistics released by FAO in 2006). In South Africa goats are found predominantly in the Eastern Cape (EC 2 483 811), Limpopo (LP 1 062 814), KwaZulu Natal (KZN 855 426) and North West (NW 782 860) provinces as shown in Figure 2.1.

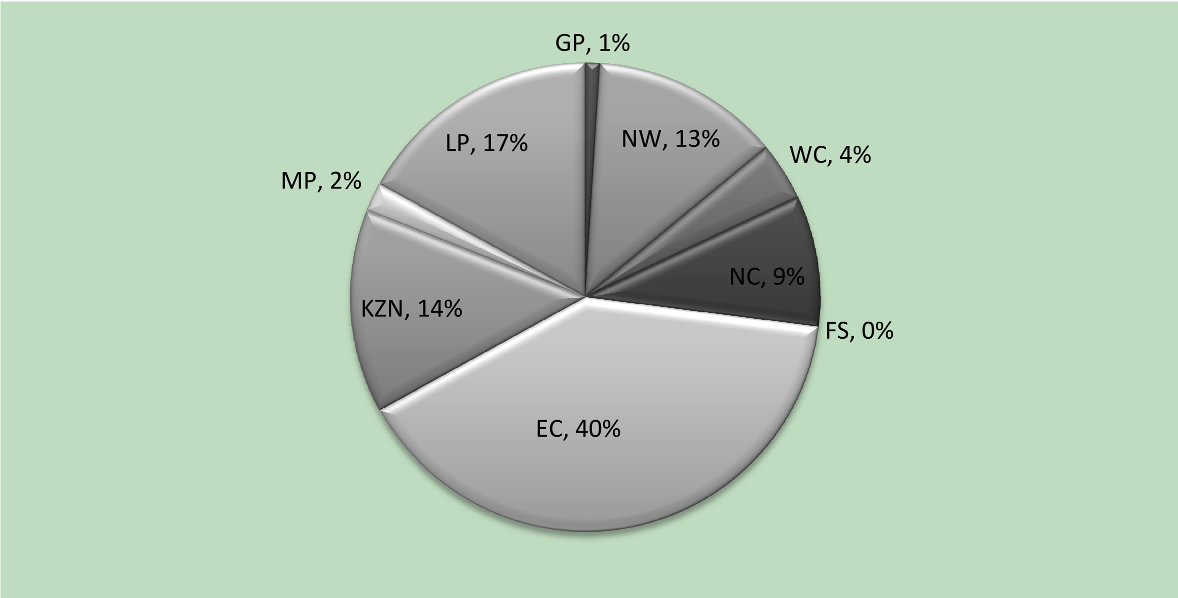

Figure 2.1. Distribution of goats in the different Provinces of South Africa (Gauteng = GP, North West = NW, Western Cape = WC, Northern Cape = NC, Free State = FS, Eastern Cape = EC, KwaZulu Natal = KZN, Mpumalanga = MP, Limpopo)

2.1.1. The Indigenous Tswana goat

The majority of goats and sheep in Africa are indigenous types, although both species were originally domesticated in Asia (Bjelland & Grøva, 1997). Their genetic resources have evolved under the stress of the African environment and are well adapted to the local conditions. Indigenous types constitute over 95% of the small ruminant population of Africa (Rege, 1994). However, there are hardly any indigenous goats which have been adequately characterised. The goats are owned by the majority of small-scale rural farmers, for whom this resource is critical for nutrition and income.

In the past, South Africa possessed a wealth of indigenous livestock which were well adapted to the harsh environment of this region. The majority of the indigenous livestock were traditionally kept under substantially lower levels of nutrition, management, disease control and higher temperatures than exotic breeds. The desired characteristics of these breeds were, therefore, masked to such an extent that they were generally regarded as inferior to the exotic breeds (Bjelland & Grøva, 1997).

The Tswana goat is a multicoloured medium size breed with long lopping ears, short coarse hair structure and is predominantly bearded and horned (Katangole *et al*., 1996). The apparent wide variation in coat colours and hair structure among Tswana goats is indicative of the fact that the breed has not been purified through selection and therefore great opportunities exist for its improvement. The propensity towards white coat colour and/or white in combination with other colours especially black and brown, appears to be an adaptive trait to withstand pronounced seasonal fluctuations in the intensity and duration of light, heat and cold (German, 2008). Tswana goats are mainly found in Botswana and Bophuthatswana (Mafikeng) (FAO, 1991).

In the arid and semi-arid regions, indigenous goats should be the cornerstones of livestock production in both commercial and communal sectors. Their supposedly inferior production was a misconception due to a very narrow definition of production. If production is simply measured as growth rate or milk production per animal, then the European breeds outperform the indigenous breeds. But if maintenance cost, reproduction and mortality are considered, then indigenous breeds often outperform the so-called improved breeds (De Lange, 1994).

The accelerating demand of a growing human population and the pressure of economic development, are affecting the security and survival of many indigenous African breeds. Indigenous breeds are, therefore, threatened, even though they have been naturally selected for the local environments and are therefore best adapted (Bjelland & Grøva, 1997).

On the basis of body size and height at the withers, the Tswana goat can be classified as a medium size breed, according to one of the goat classification criteria suggested by Devendra and McLeroy (1988). Male goats generally grow faster and are heavier with superior body conformational measurements than female goats. Age significantly affects body traits. Tswana goats breed all year round. The recovery capacity of goats from drought is remarkable and is due to their efficient reproductive behaviour which includes twinning and shorter kidding intervals. Tswana goats have low maintenance requirements which become an advantage in unfavourable environments (Horst, 1984).

2.1.2. The Improved Boer goat

The origin of the Boer goats is vague and probably rooted in ancestors kept by Namaqua Hottentots and migrating tribes of "Southern Bantu" people. The Boer goat is an improved indigenous breed, which consist of a mixture of blood from various goats, principally those from Eastern countries and India (Erasmus, 2000). The occurrence of polledness indicates some possible influences of the European, Dutch dairy goat (Steele, 1996). Considering migratory and trade practices of early inhabitants of Southern Africa, it seems evident that the Boer goats contain genes from these pools. The Boer goat was observed as early as 1661. The noun "Boer'' means farmer in Dutch, and was used to distinguish the Boer goats from the Angoras imported in the nineteenth century (Casey & Van Niekerk, 1988).

Three types of un-improved Boer goats are recognised (Devendra & McLeroy, 1982): common Boer goat, medium in size, with short glossy coat which is white in colour with brown spots on reddish brown heads and necks; long-haired Boer goat, larger, heavier and late maturing; and polled multi-coloured Boer goat with distinct dairy conformation, suggestive of the influence of introduced milk breeds.

The fact that makes the breeding history of the improved Boer goat unique is that the breed was not created from two or more pure breeds, as is the case with other varieties of animals bred in South Africa. Rather, the prototype for the breed was selected from all existing breeds of goats in South Africa to achieve the functional characteristics and type as they are today, hence the name improved (or ennobled) Boer goat (Malan, 2000). This pioneer work was chiefly carried out by a handful of farmers in the Eastern Cape, particularly in the district of Somerset East. The highlight in the history of the Boer goat was when the Boer Goat Breeders Association of South Africa was founded on 4 July 1959 at Somerset East (Casey & Van Niekerk, 1988; Malan, 2000).

The South African Boer Goat Breeders Association adopted a purposeful breeding policy and applied strict selection guidelines. Breed standards stipulate the ideal colour of the improved Boer goat to be white with a red head and blaze. A limited number of red patches are allowed. A pigmented skin is preferred, particularly in areas with no hair cover. Furthermore, they must be robust, with good conformation and have a Roman nose. Legs must be short, well fleshed with good thighs and hind quarters, which is important for good carcass characteristics (Casey & Van Niekerk, 1988). The improved Boer goat is a remarkable small-stock ruminant that posses distinctive qualities enabling it to excel as an efficient red meat producer (Erasmus, 2000).

Boer goats are very fertile and not seasonal breeders. The goats have multiple births with an average kidding percentage of 180 which exceeds the average attained by other livestock. They are early maturing and at the age of one to one and a half years, a significant number of ewes produce multiple kids. The mean body weight of the adult ram varies between 100 and 120 kg while that of does varies between 70 and 80 kg (Erasmus, 2000; Malan, 2000). The Boer goat yields lean meat of high quality which is succulent, tender, extremely attractive and tasty (Malan, 2000). Goats should be marketed between the ages of 6 to 15 months and the carcass should weigh no more than 23 kg. Growth rate of kids is associated with sufficient milk production by the doe and good mothering instincts (Casey & van Niekerk, 1998; Erasmus, 2000). The Boer goat is able to maintain economic production up to the age of approximately 10 years (Malan 2000).

2.2. Importance of goats

The special attributes of goats that make them particularly important in rural resource poor communities compared to other domestic ruminants include: ability to graze and utilize a wide range of poor quality forages and browse (Misra & Singh, 2002; Keskin *et al*., 2005); ability to walk long distances in search of feed (Morand-Fehr *et al*., 2004); short generation intervals and high reproductive rates; high turnover rates on investment and hence low risk on investment (Lebbie, 2004); low maintenance costs (Misra & Singh, 2002); high energetic efficiency of milk production; efficient utilization of marginal lands; smaller carcasses which are conveniently marketed or consumed over a short time period which is an important factor in rural areas without cold storage; and a good flocking instinct which makes herding by younger and older members of the family possible (Malan, 2000; Lebbie, 2004).

Within the African society, goats comprise a great proportion of the total wealth of poor households (Peacock, 1996). In general, goats do not contribute much to direct income earnings in rural households. As tangible financial assets, however, goat product consumption and sales enhance economic stability of households in times of crop failures and currency fluctuations (Lebbie, 2004; Morand-Fehr *et al*., 2004). Goats provide immediate cash to meet day to day family needs and off-farm inputs for crop production and thus contribute to the sustainability of agricultural production (Misra & Singh, 2002; Morand-Fehr *et al*., 2004). Goat keepers assist in meeting local demands for animal products but also indirectly enhance national economic stability through the reduction of foreign currency expenditure on importation of these products to meet domestic demands. Goat keeping provides employment for the rural poor women and their children, whose responsibility is to take care of the goats (Lebbie, 2004).

Goats contribute meat, milk, fibre, leather and other functions that are significant to the productivity, stability and sustenance of many farming systems (Sheridan *et al*., 2003; Anbarasu, *et al*., 2004; Lebbie, 2004; Sahlu, *et al*., 2004; Salem & Smith, 2008: Lu *et al*., 2010). Goats in developing countries are generally an integral, but not dominant component of complex agricultural systems. It is in countries with low per capita income (less than US $150) that goats are heavily concentrated, especially in South East Asian region and in the sub-Saharan Africa, where estimates show that approximately 70% of the human population is undernourished (Devendra, 1981). It is believed that goats could make a much greater contribution towards meeting the protein needs in developing countries (Bjelland & Grøva, 1997). The potential for goats to contribute to the attainment of food security, economic development and environmental sustainability is tremendous (Lebbie, 2004; Sahlu *et al*., 2004).

Goats have a number of biological and behavioural characteristics that make them preferable to cattle and other large ruminants. Goats produce more meat and milk per unit of feed than other ruminants (Okello & Obwolo, 1985). Most goat populations inhabit harsh environments with extreme climatic fluctuations (Iniguez, 2004; Morand-Fehr, 2004). The ability of goats to adapt to a wide range of climatic and nutritional conditions could possibly be accounted for by their unspecialised grazing habits and their ability to assume a bi-pedal stance that greatly maximises the available grass and tree stratum within a given area (Lu, 1988; Mellado *et al.,* 2004). In arid and semi-arid regions, the harsh environments cannot support crop production in a reliable manner. The communities in these environments depend largely on indigenous livestock breeds raised under traditional nomadic and transhumant pastoral systems based upon communal grazing. Goats, because of their unique adaptive capacity to harsh environments, feature very well among the households (Lebbie, 2004).

The most common concept of goats influencing the vegetation is their use as a biological means of controlling bush encroachment (Morand-Fehr *et al*., 2004; Yayneshet *et al*., 2008) in mixed livestock systems, thereby optimising the use of diverse rangeland resources (Dziba *et al*., 2003; Torrano & Valderrábano, 2005). It has been well documented (Merril & Taylor, 1981; Morand-Fehr *et al*., 2004) that goats can be used to positively modify the vegetation cover, particularly to clear areas rich in bushes, shrubs, thorny vegetation or under the canopy in woods, so that afterwards other species such as cattle and sheep can graze a more nutritive vegetation and have more open areas, while at the same time the spread of veld fires can be reduced or avoided.

Goats have been successfully utilized for the biological control of weeds and the improvement of grazing capacity of ranges (Radcliffe, 1985; Lebbie, 2004). In mixed species situations, goats complement cattle and sheep rather than compete with them for feed, because of their inherent ability to utilise a wide variety of plant species (Lebbie, 2004).

Manure and urine from goats is an invaluable source of organic fertilizer for maintaining or improving agricultural production (Lebbie, 2004; Azeez *et al*., 2010). While its contribution is limited, it is important where most rural goat keepers cannot afford the expensive inorganic fertilizers for use in their traditional low-input crops and horticultural production systems (Lebbie, 2004).

Most studies have shown that roughages with a higher fibre and low nitrogen contents are digested to a greater extent in goats than in sheep (Sheridan *et al*., 2003; Morand-Fehr *et al*., 2004; Gazmi-Boubaker *et al*., 2006). Thus it has been suggested that goats would be superior to sheep in digesting forage cell wall (Domingue *et al*., 1991; Morand-Fehr *et al*., 2004). Goats have been shown to be also more efficient at digesting tannin-rich feedstuffs (Odenyo *et al*., 1999) and the ability to detoxify higher amounts of tannins compared to other ruminants (Silanikove *et al*., 1996).

Special feeding habits of goats typical for the species differ from those of other ruminants and are the basis for much of the criticism directed at goats. It is often suggested that goats are destructive grazers (Bellingham *et al*., 2010), grazing more closely on bushes and grass, thereby reducing chances of plant regeneration from seedlings (Gihad *et al*., 1980; Lebbie, 2004; Morand-Fehr *et al*., 2004; Animut & Goetsch, 2008). However, Gihad (1976) and Morand-Fehr *et al*., (2004) reported that those criticisms of the goat are really a result of overstocking and the lack of good, scientific husbandry and management.

2.3. The natural vegetation

At least one third of the world's land surface may be considered natural grazing grounds (Le Houèrou, 1980). Natural grazing is our most valuable natural resource as it is the basis for animal production (De Lange, 1991; Sanon *et al.*, 2007) contributing to the protein supply of mankind. The rangelands of Southern Africa support diverse and dynamic ecosystems that sustain wildlife, game and livestock farming (Tefera *et al.*, 2008). The most important use of vegetation is as a nutrient source for many grazing animals (Kawas *et al.*, 2010), and is thus changed with regard to the diversity and structure by the herbivores (Hodgson & Illius, 1996). Grazing ruminants thus form the backbone of most of the world's ruminant livestock enterprises (Gordon, 1995).

In Africa, over 250 million head of domestic animals live in natural grazing areas, classified as arid, semi-arid and montane, where browse plays an essential role in animal production (Le Houérone, 1980). Approximately 80% of the total area of South Africa consist of meadows and pastures (Britannica World Data, 1988) much of this being semi-arid. In semi-arid Savannah, two clearly defined forage resources are available: grass and bush. Forages provide an important source of minerals for ruminants in preventing diseases and stimulating ruminal microbial activity (Spears, 1994). Viewed holistically, the most economic farming system here would be one where browse and grass are used together in order to achieve maximum sustained production per unit area (Aucamp *et al.*, 1985). Sustainable use of this valuable resource, which ruminants convert to food and other products for human consumption, is essential for the well being of the rural population (Bjelland & Grøva, 1997).

In South Africa, pastoralism or extensive animal farming is the most widely practised form of land use, as almost 75% of the agricultural area in South Africa is suitable for extensive livestock production only (Raats, 1996). The amount of forage available to grazing animals depends on season, but is also influenced by land-use patterns (Schlecht *et al*, 2006). Thus, for the purpose of maintaining sufficient growth and reproductive performance, animal producers and wildlife managers need to comprehend the heterogeneity, variability and nutritional changes of ranges (Ramirez *et al.*, 2004; Agreil & Meuret, 2004). This indicates the extent of implications and potential of knowledge on the science of free range ruminants. Understanding the foraging strategy in combination with the anatomical and physiological adaptation of goats is important for the management of both vegetation and goats in traditional pastoral systems (Mellado, 2005).

2.4. Feeding behaviour of goats

Free ranging animals respond to the quantity and distribution of vegetation on offer by altering their foraging behaviour (Gordon, 1995). The primary foraging variables which researchers are interested in are time spent on, feeding activities (browsing/grazing and plant species selection), non-feeding activities (walking, standing, lying, drinking) and rumination.

2.4.1. Grazing and browsing

Goats are opportunistic foragers (Lu, 1988; Sharma *et al*., 1998; Ngwa *et al*., 2000; Kawas *et al*., 2010) that can adapt to a wide range of climatic and nutritional conditions as well as rough country (Gihad *et al*., 1980; Animut & Goetsch; 2008). The ability of goats to adapt to these conditions could possibly be accounted for by their higher tolerance for bitter substances and their relatively unspecialised feeding habits. The use of browse by goats is probably an important factor where herbaceous forage quality is poor and does not provide minimal nutrition to support cattle and sheep (Sidahmed *et al*., 1981; Papachristou, 1996; Animut & Goetsch; 2008). The high degree of browsing by goats could be due to several morphological features related to the foraging behaviour which apparently contribute to the goat's success as a browser. These include the mobile upper lip and tongue that give goats a greater ability to harvest forages from the shortest grasses and forbs to the thorniest shrubs (Lu, 1988; Mellado *et al*., 2004) and the ability to assume a bi-pedal stance when feeding (Taylor & Kothman, 1990; Ngwa *et al*., 2000; Mellado *et al*., 2004). Among domestic animals, goats alone seem to possess this bi-pedal stance trait (Ngwa, *et al*., 2000). The bi-pedal stance greatly maximises the available grass and tree stratum within a given area and gives goats the advantage of foraging overhead, thus increasing the quantity of forage available in wood and shrub lands (Lu, 1988; Ngwa, *et al*., 2000).

Browsing horizons up to 2m in height by goats commonly occur in areas where trees and hanging vines are abundant (Lu, 1988). This is particularly important during the dry season when the ground layer forage is either dry or depleted from grazing and decomposition (Ngwa *et al*., 2000). Goats in arid environments survive on diets composed mostly of browse (Ramirez *et* *al*., 1993; Provenza, 1995; Ammar *et al*., 2008; Ramírez-Orduña *et al*., 2008; Kumara Mahipala *et al*, 2009), which is least affected by drought (Silanikove, 2002). Kadzere (1995) suggested that in southern Africa, the importance of browse increases with increasing aridity.

Goats will walk long distances in search for food (Bjelland & Grøva, 1997) and are thus exposed to a greater variety of forage species (Gihad *et al*., 1980). The extent of travelling is dependent on forage availability, water resources, comfortable resting areas, season of the year, size of the goat and other animal factors. Goats are alert and inquisitive in their environment (Sharma *et al*., 1998). Eye level feeding is a common foraging posture and has been considered a valuable mechanism for protection from predators. A secondary benefit from this behaviour is the reduction of the risk of infection by parasite eggs found on surface vegetation (Lu, 1988). Although goats generally orient towards the wind, they have been observed to evaluate an area upon arrival and subsequently direct the foraging path towards brushy areas (McMahan, 1964).

Based on their ability to browse shrub, grass and tree foliage, ruminant species have been classified as grazers or browsers (Gordon, 2003). Goats are neither exclusively grazers nor exclusively browsers (Lu, 1988). Goats are able to graze short grass and to browse on foliage not normally eaten by other domestic livestock. The exceptional economic value of goats lies precisely in their ability to utilise certain plants which are less appetising to other stock breeds (Malan, 2000). Goats, being the most rugged grazers of domestic livestock, prefer browse plants which form approximately 60% of their diet, the other 30% is made up of grasses and 10% of selected forbs when available (Gihad *et. al*., 1980, Malecheck & Provenza, 1981). This shows a heavier dependency of goats on browse, irrespective of the presence of the opportunity to choose between browsing and grazing (Lu, 1988).

The shift between browsing and grazing by goats is largely dependent on the availability of browse and grass (Lu, 1988; Mogorosi *et al*., 1996; Dziba & Raats, 1998). The ratio between grazing and browsing, is however, subject to drastic change, depending on prevailing conditions (Lu, 1988; Raats & Tainton, 1992). Seasonal and geographic variations and intensity of stocking appear to influence the nature of the intake (Pontes *et al*., 2010).

Goats have thus developed a unique feeding behaviour (Raats & Tainton, 1992) which set them apart from other species of livestock (Lu, 1987). The unique feeding behaviour together with the inquisitive feeding habits, enables goats to thrive in dry areas receiving less than 750 mm of rainfall (Bjelland & Grøva, 1997) and with little high quality forage (Ouedraogo-Kone *et al*., 2006). The foraging behaviour is central to understanding plant-herbivore interactions, efficient management of gazing systems and eventual profitability of the livestock enterprise (Ungar, 1996; Torrano & Valderrábano, 2005; Sanon *et al*., 2007).

2.4.2. Plant species selection and plant preference

Under rangeland conditions, the herbivore is surrounded by an apparent super-abundance of potential food items (Mogorosi, 2000). Grazing herbivores select from structurally and chemically diverse spectrum (Fraser *et al*., 2009). Selection of individual sward components by grazing herbivores can influence animal performance through variation in both the quality and quantity of ingested forage material (Wilmhurst *et al*., 1999). Diet selection is a functional category of the general feeding behaviour of animals and is defined in terms of the outcomes of behaviour (Hughes, 1993). The fact that grazing herbivores exhibit dietary selection has long been established (Emlen, 1966; Bell, 1971; Raats, 1993; Sun *et al*., 2008), but the basis upon which animals select their diets has been a point of contention among scientists (Dziba, 2000).

Several hypotheses have been suggested to explain diet selection. Some experiments have advocated diet selection based on intake rate (Spalinger *et al*., 1986), or nutritional balance (Alonzo-Diaz *et al*., 2008; Berteaux *et al*., 1998; Rafferty & Lamont, 2007; Sanon *et al*., 2007; Baraza *et al*., 2009; Stolter *et al*., 2009), while others suggested that the density of the vegetation (plant species and the relative abundance of each) is the basis of selection (Black & Kenney, 1984; Merril & Taylor, 1981; Murden & Risenhoover, 1993; Barroso *et al*., 1995; Schlecht *et al*., 2006; Sanon *et al*., 2007). Others suggest that plant height and species mixture is the basis of the discrimination (Newman *et al*., 1995). The ability of the animal to select sufficient quantities of nutritious plant material is affected by animal related factors (genetic makeup, prior experience or conditioning, prevailing nutritional and the physiological state of the animal) as well as environmental factors (environmental temperature due to seasonality, topography, heterogeneity of the vegetation, availability or abundance of various plant species (Raats & Tainton 1992; Keskin *et al*., 2005; Celaya *et al*., 2007; Ellis *et al*., 2005). What a goat actually chooses to eat is determined by the selection criteria which will alter as the relative quantities and qualities of items change (Pellew, 1984). Most importantly, the understanding of the relationship between resource availability and intake rate underlies the prediction of foraging choices in heterogeneous systems (Spalinger *et al*., 1988, Ungar, 1996)

Goats are more selective feeders than cattle and sheep (Van Soest, 1982). Diet selection is a major determinant of animal and plant production through its effect on sward structure and plant parts remaining for selection as time passes. Plant species selection or preference and physical activities (feeding/non-feeding) constitute an important part of behaviour of range animals (Bjelland & Grøva, 1997). Preference or acceptability indices can be used as evidence of feed selectivity and to rank different species, in a given environment, in terms of their relative acceptability by a category of animals (Owen-Smith & Cooper, 1987). Preference indices are useful tools for different management decisions, such as determining carrying capacity studying plant-animal interactions and modelling range utilisation (Nelson, 1978; Duncan, 1983).

It appears that the physical structure of plants, and its interaction with nutritional value (Westoby, 1978; Fraser *et al*., 2009), plays an important role in feed selectivity of goats (Genin & Pijoan, 1993). Goats tend to select a diet containing a higher proportion of green leaves and a lower proportion of stems and dead material than is in the pasture (Flachowsky & Tiroke, 1993). The fractions which goats most often select, the buds, leaves, fruits and flowers, contain less fibre and more protein and are thus more digestible than stems and petioles (Lu, 1988; Ouedraogo-Kone *et al*., 2006; El Aich *et al*., 2007; Baraza *et al*., 2009). Alonso-Diaz *et al*., (2008) state that goats may be able to discriminate among feeds in order to select those with higher digestibility.

Animals expand their diet to include other food types as food availability from favoured species decline over the seasonal cycle (Owen-Smith, 1997; Alonso-Díaz *et al*., 2008; Yayneshet *et al*., 2008). Animals may also increase their feeding duration in patches of food plants and adjust foraging paths (Ungar, 1996). Diet selection may also be affected by period of occupation and stocking rate (Mbuti *et al*., 1996; Raats *et al*., 1996a).

The most direct influence animals have on the plant community is through their diet selection (Hughes, 1993). Diet selection is important for understanding fundamental ecological interactions between animals and their habitat (Pyke, 1984). It also determines which plants are consumed and where, when and to what degree they are consumed (Gordon, 1995). Diet selection, therefore, is a central process in the herbivore plant interactions, with consequences to the structure, species composition and ecological relations of plant communities and their ecosystems (Nantis, 1997; Illius *et al*., 1999).

2.4.3. Diurnal variation in feeding

It is known that ruminants can have 8 and 10 grazing periods per day (Arnold, 1962). Diurnal variation in the feeding behaviour of goats has been observed by Dumont *et al*., (1995) and Bjelland & Grøva (1997). Similar variations were also found in the diet composition of fistulated animals, in nitrogen content (Langlands, 1965; Hodgson, 1969; Obioha *et al*., 1970), lignin (Obioha *et al*., 1970), digestibility (Hodgson, 1969) and botanical composition (Coates e*t al*., 1987). Two major feeding periods are normally recognised in both extensive and intensive systems (Lu, 1988). Askins & Turner (1972) reported that the morning feeding period commenced at daylight and continued until mid morning. The second major meal began about 3 hours prior to sunset and lasted until darkness. Minor meals were reported to last about 1 hour and occurred at mid-day. However, this diurnal pattern is modified by factors such as frequency of feeding, amount of feeding, forage availability and environmental stress such as heat and rain (Lu, 1988). In their study, feeding behaviour of goats changed extensively throughout the day. On average, morning feeding period was dominated by browsing (43%) while grazing was the dominant activity in the afternoon (41%).

2.4.4. Rumination and non-feeding activities

Goats can spend more than one-third of their time ruminating (Lu, 1988). Bell & Lawn (1957) reported that the time spent ruminating ranged from 3 hours 22 minutes to 13 hours 12 minutes per day in apparently healthy goats. Lu (1987) on the other hand reported that the average time spent in ruminating ranged from 5 hours 48 minutes to 7 hours per day in goats depending upon the particle length of forage. Bell & Lawn (1957) reported that during the night hours (20h00 to 08h00) a large portion of the time was spent on rumination. Forage particle length, amount of forage fed and thermal stress are some of the factors affecting rumination time in goats. Forage particle length and amount of forage fed are positively correlated with rumination time (Lu, 1987) while environmental temperature is negatively correlated (Appleman & Delouche, 1958). Goats have been observed to spend (31%) of their time on non- feeding activities both in the morning and afternoon feeding periods (Bjelland & Grøva, 1997).

2.5. Techniques to measure the foraging strategy of free-ranging goats

The present review on techniques to measure the foraging strategy of goats is extensively based on the review by Gordon (1995) and will be limited to animal-based techniques only.

2.5.1. Feeding behaviour

The oldest and most frequently used method for measuring feeding behaviour is by direct observation, usually recording events with a manually operated data logger or video recorder. As with most observational techniques, this method is time consuming, it is difficult to collect data over a 24 hour period without night vision equipment, and the presence of a human observer can alter the behaviour of even tame animals (Gordon, 1995). To avoid these problems, a number of mechanical and electronic devices have been developed to measure one or more of these variables automatically. These systems monitor leg or jaw movements (Penning, 1983; Alkon *et al*., 1989; Janeau *et al*., 1987; Matsui & Okubo, 1989) for estimating the rate and interval between bites and grazing time which allows the differentiation between grazing and ruminating. Most of these devices were developed for use on cultivated pastures and are generally found less effective under natural grazing conditions due to the transducer being punctured by thorns.

2.5.2. Intake rate

Reviews on the methodology to determine the intake of grazing ruminants are available by Van Dyne (1969), Cordova *et al.* (1978) and Allison (1985). Generally, intake is divided into short- and long-term intake rates. Short-term intake rate is normally measured over a period of not more than one hour and is defined as a combination of bite size and rate of biting, with units given in mg s^{-1} or g min^{-1}. A number of techniques are available to estimate the short-term intake rate. Firstly, it can be estimated by the visual monitoring of the size and rate of bites from tamed, free ranging animals, followed by clipping or hand-plucking simulated bites from the vegetation (Bjugstad *et al*., 1970). Secondly, changes in body mass during grazing, using very accurate balances or pressure transducers attached under each hoof, are used to determine short-term intake rates (Penning & Hooper, 1985). The third option is to determine the number of boluses swallowed by measuring the changes in the geometry of the oesophagus (Stuth *et al*., 1981) or the change in the conductance or pressure on an oesophageal cannula (Forwood *et al*., 1985) with the passing of food boluses down the oesophagus. Finally, short-term intake rate and bite size can be estimated from the amount of extrusa obtained from oesophageal fistulates over a known time period and the simultaneous recording of bite rates (Stobbs, 1973). The development of the remote controlled oesophageal fistula valve (Raats & Clarke, 1992) makes it possible to even measure harvesting rates per bite or unit time of specific plant species under free range conditions (Mogorosi *et al*., 1996). According to Gordon (1995), the oesophageal fistula method appears to provide the most accurate estimate of intake rate per bite. An alternative approach to estimate short-term intake rate is to present plant material to animals confined in pens, arenas or using a ‘grazing cage’ (Burlison *et al*., 1991; Gordon, 1995).

Techniques for measuring long-term (daily) intake rates are based on either the rate of depletion of offered forage or the amount of herbage ingested using internal or external markers. Gordon (1995) states that the majority of pasture-based methods are of limited value except on simple swards. The reasons for the limited value are (a) errors associated with measurement of pasture growth and senescence, (b) the difficulty in estimating intake from vegetation community mosaics, (c) the inability to provide estimates of between-animal variation in intake and (d) problems in estimating intake by individual animal species in multispecies grazing systems. Markers, on the other hand, provide a more direct measure, though the estimation of faecal output and digestibility on which this method relies, has its own set of problems and errors. More recently, however, the use of long-chain *n*-alkanes as both internal and external markers (Mayes *et al.*, 1986; Dove & Mayes, 2005) has been proven very effective in determining diet digestibility and intake in a number of animal species (Oliván *et al.*, 2007). The use of slow release capsules (Mayes *et al.*, 1991) which deliver a constant dose over a period of up to 30 days (20 days sampling), further improved the accuracy of this method and avoid the need for frequent dosing of animals.

2.5.3. Diet composition

Reviews on the methodology to determine diet composition of grazing ruminants are available by Harris *et al.* (1967), Van Dyne (1969), Theurer *et al.* (1976), Van Dyne *et al.* (1980), Holechek & Vavra (1981), Holechek (1982) and McInnis *et al.* (1983). A number of techniques are available for determining species selection or preference of grazers and browsers. These include: visual observations (animal and plant based), tiller/branch marking (plant based), faecal microscope and *n*-alkane techniques. To obtain results on species selection or preference of browse/graze in this study, animal and plant based techniques were used. A popular method to obtain qualitative estimates (plant species preference) is to follow an animal and record the species that are grazed/browsed. Obtaining, simultaneously, clipped or hand-plucked samples which mimic each bite taken and recording of time and bite size (Decandia *et al*., 2000) could supply additional quantitative data on the nutrient composition of the diet (Bryant *et al*., 1981). Major disadvantages of this technique are the difficulty of identifying grass species in a mixed vegetation (Holechek *et al*., 1982) and the error involved in clipped or hand-plucked samples (Langlands, 1974). Alternatively, the micro-histological examination of plant fragments (usually cuticle) in the oesophageal extrusa, alimentary tract or faeces can be used to obtain qualitative information on diet composition (Crocker, 1959; Ward, 1970; Dove & Mayes, 2005). Oesophageal fistulated animals have been used widely to determine the diets of domesticated livestock (Vavra *et al.*, 1978) and is accepted as the most accurate method available for this purpose (McInnis *et al.*, 1983) provided proper protocols and management are implemented.

2.5.4. Location of animals in the field

The decision-making processes invoked by the foraging animal may differ in relation to the landform scale (Senft *et al.*, 1987; Stuth, 1991) and spatial dispersion of resources (Gordon, 1989). Traditionally, information on the location of animals was gathered by direct observation (Arnold, 1984). In order to overcome some of the problems associated with this method, highly advanced technology, such as rodiotelemetry (Warren & Mysterud, 1991) and Global Positioning Systems (GPS) (Roberts *et al.*, 1993) to track animals and record their positions are being used to monitor the position of free range animals.

Grazing ecologists, today, have a wide variety of techniques available to measure components of foraging strategy. Of these techniques, Gordon (1995) states that: “There is no ‘best’ technique for measuring foraging strategy. The most appropriate technique will depend upon the goals of the research and the circumstances under which the measurements are made including such circumstances as the time scale of the study, grain of heterogeneity, the availability of tame animals, logistics and funding”.

In view of the fact that oesophageal fistulated animals were used to collect the samples that were used to determine plant species composition and nutrient content of the diet selected by free ranging goats, it is appropriate to discuss these specific techniques as well as the development and validity of the valve technique at this point.

2.5.5. The oesophageal fistula valve technique

The prototype fistula valve technique developed by Raats and Clarke (1992), consists of an oesophageal fistula valve which allows the fistula to be opened and closed, a rechargeable battery pack and motor to operate the valve, a remote controller and receiver to activate the valve motor, and a harness to attach the equipment to the body of the animal. This sampling system is generally referred to as the oesophageal fistula valve technique. In most respects, this technique is identical to the standard oesophageal fistula (bag) technique (Torell, 1954), with the added advantage that the number and size of extrusa samples can be varied and collected throughout the day.

The development of the fistula valve technique (Raats & Clarke, 1992) substantially improved the versatility of this technique. Raats (1993) listed four improvements to the standard fistula technique, namely: (a) The collection of different numbers and sizes of samples throughout the day is possible without disturbing the animals' normal feeding behaviour. (b) The collection of forage samples as selected by goats in extensive areas having heterogeneous plant populations is possible. (c) Sampling from specific plants or plant communities is facilitated. (d) The need to starve animals overnight in order to reduce the possibility of extrusa samples being contaminated with rumen contents is obviated. Since the development and testing of the first prototype sampling system, further improvements were made to the fistula valve, radio and receiver. Specific adaptations for use in goats have recently been made (Booyse *et al*., 2009) and the new fistula valve was used in the present study.

2.6. Estimating digestibility of forages selected by free ranging goats

The potential value of a feed for supplying a particular nutrient can be determined by chemical analysis, but the actual value of the food to the animal can be arrived at only after making allowances for the inevitable losses that occur during digestion, absorption and metabolism (McDonald *et al*., 2002). The performance of the herbivores when grazing, depend directly on forage digestibility and intake (Ramírez *et al*., 2000; Decruyenaere *et al*., 2009). Evaluation of feeds should provide nutritionists with the necessary information to formulate a diet from both a physiological and an economical point of view, in order to optimize the animal performance. One of the most useful measures of the nutritional value of feedstuff is its apparent dry matter digestibility (Omed *et al*., 1989). Digestibility provides the best practical evaluation of the quality of the grazing animal's diet because it indicates the portion that can actually be used by the animal's body.

2.6.1. Laboratory methods of estimating digestibility

Digestibility can be measured *in vivo* (in the animal), *in situ* (in a bag) and *in vitro* (in glass).

2.6.1.1. *In vivo* digestion

Digestion trials are an excellent way to evaluate feedstuffs. Forage is fed to several animals and the amount of forage fed and faeces produced in a 10-14 day period measured, recorded and sampled for analyses. Feeds offered and refused feeds are used to determine dry matter intake (DMI). The faecal output is determined by total collection of faeces by a tray or a faecal bag. From this, apparent dry matter digestibility (ADMD) can be determined by assuming that DMD of the forage is the difference between DMI and faecal output (Mc Donald *et al*., 2002). The method is effective for confined animals. *In vivo* determination is a standard method for digestibility testing, but it is laborious and expensive as it requires a substantial number of animals and large amounts of feed (Omed *et al.,* 1989; Decruyenaere *et al*., 2009; Karlsson *et al*., 2009). Dohme *et al*. (2007) states that *in vivo* trials are not feasible for routine evaluation of a high number of different specific forages. Several laboratory methods have been proposed for its estimation and include *in vitro* and *in sacco* techniques.

2.6.1.2. *In vitro* digestion

The *in vitro* or artificial rumen technique has become the commonly used procedure for estimating forage or diet sample digestibility (Holechek *et al*., 1982) and nutritive value. This technique attempts to simulate natural ruminant digestion under laboratory conditions. Although a number of artificial rumen procedures have been used, the Tilley and Terry (1963) two-stage technique has become the standard. It involves an initial fermentation of the sample with rumen micro-organisms followed by inoculation with an acid pepsin solution for digestion of protein residues.

Pearson (1970) and Kartcher & Campbell (1979) provide reviews on the sources of variation associated with the Tilley and Terry (1963). Uresk *et al*., (1975) found rumen inoculum followed by hydrochloric acid accounted for most of the digestibility when the Tilley and Terry (1963) technique was used. However, additional digestion by pepsin was not significant. Research reported by Smith *et al*., (1971) showed that silica reduced *in vitro* digestibility by about 2 percentage units for each percentage unit increase in the silica content of the forage. Their study indicates that the *in vitro* digestibility data should be presented on an organic matter basis (Holechek *et al*., 1982).

Considerable research shows that the species of animal used as an inoculum source for *in vitro* digestion is not important if the donor animal is fed a diet similar to the diet under evaluation (Cowan *et al*., 1970 & Scales *et al*., 1974). The number of animals needed as inoculum donors has not been well established. Van Dyne & Weir (1964) reported that replication was needed but Scales *et al*., (1974) did not find any increase in predicative ability when inoculum composited from several animals was compared to that from one animal.

Pearson (1970) and Kartcher & Campbell (1979) reviewed the period of time required for incubation. A 48 hour period for both fermentation and acid-pepsin digestion has become standard on the basis of research by Tilley & Terry, (1960), Van Dyne (1962) and Pearson (1970). Several studies have shown that *in vitro* digestibility can give an accurate evaluation of actual digestibility (Tilley & Terry, 1963; Palmer & Cowan, 1980). The two-stage technique (Tilley & Terry, 1963) was developed as an end-point digestibility method and thus, unless lengthy and labour intensive time-course studies are completed, the technique does not provide information on the kinetics of forage digestion (Theodorou *et al*., 1994).

2.6.1.3. *In sacco* or *in situ* digestion

Rumen degradability has been measured in several laboratories by the nylon bag technique. The nylon bag technique also called the *in sacco* or *in situ* technique is based on depositing feedstuffs into separate bags which are incubated in the rumen of several rumen cannulated animals fed standardised diets for appropriate time intervals (Spanghero *et al*., 2003). The main objective is to measure the rate of disappearance of dry matter and other nutrients. It thus provides a useful means of evaluating the rate of disappearance of feed constituents from specific plants or diets placed in the bags and incubated in the rumen for varying periods (Kandylis & Nikokyris, 1991). After a prescribed period of incubation the samples are removed, washed, dried and weighed. Degradability (or disappearance) of the substrate is determined by the weight loss during the incubation periods.

The nylon bag technique has been used by many workers in order to estimate the ruminal dry matter and protein degradation during the evaluation of the nutritive value of feedstuffs for animal production (Dohme *et al*., 2007). Nylon bags have also been used to predict energy values of concentrates, and in this context they have been more accurate than the analytical data, enzymatic degradation and *in vitro* digestibility (Sauvant *et al*., 1985). The nylon bag technique thus provides a means of ranking feeds according to the rate and extent of degradation of dry matter, organic matter, nitrogen and other nutrients. This method is most appropriate for providing information on nutritive value of feeds for ruminants and is a powerful tool for improving our understanding of the processes of degradation which occur in the rumen (Ørskov *et al*., 1980; Dohme *et al*., 2007).

As nylon bags are usually used to contain the forage, free movement in the rumen does not occur and true *in vivo* conditions are thus not obtained with this method, leading to the technique now becoming known as the *in situ* technique (Osuji *et al*., 1993). Various materials have been used in the construction of the bags (Ørskov *et al*., 1980). In early experiments (Quin *et al*., 1938) silk bags were used to incubate samples. These were later replaced by other types of clothes like dacron (Schoeman *et al*., 1972; Mehrez & Ørskov, 1977) nylon, and polyester.

2.7. Factors affecting ruminal dry matter and protein degradability

The main factors influencing the degradability estimates of the supplements and feedstuffs are:

2.7.1. Replication of measurements

Mehrez & Ørskov (1977) observed that the greatest source of variation of the *in sacco* technique was the host animal. It has been suggested that to measure degradabilities of dry matter and protein, a sample has to be incubated for at least two periods in three animals to give an accurate estimation for one given incubation. There is little to be gained by repeating treatments within the rumen of the same animal. The number of animals needed, will depend on the expected magnitude of the differences between treatments. There are small or no differences in the *in sacco* degradation rate from samples incubated in either sheep, goat or cattle (Ammar *et al.,* 2008; Mehrez & Ørskov, 1977). The use of cattle, in contrast to sheep and goats, has the advantage of allowing a large number of bags or larger size of bags per period.

2.7.2. The basal diet of the cannulated animal

The diet of the "host" animal can have a profound effect on the rate of degradation of the material being incubated, for example, animals given diets with a high proportion of concentrates will have reduced cellulolytic activity in the rumen. The diet chosen for the animal used will obviously depend on the purpose of the experiment.

2.7.3. Preparation of the test sample and mastication

Preparation of samples for incubation is critical as the sample should represent, as far as possible, the materials, as they would appear in the rumen had they been consumed by the animal (Ørskov, *et al.,* 1980). Therefore, the ideal sample preparation would be a masticated digesta from animals fitted with oesophageal cannula (Ørskov, 1992). As this is not feasible in most cases, it is suggested that a dry and milled sample is used instead. The dry sample should be milled through a 2.0-3.0 mm diameter sieve.

2.7.4. The rate of outflow from the rumen of unfermented feed particles

The extent to which ruminal dry matter and protein degradability varies with outflow rate depends on the rate at which the degradation of the protein proceeds. In addition several other factors can influence the accuracy of the nylon bag technique, such as:

2.7.4.1. Bag size

The optimum size of the bag has been investigated by a number of workers (Rodriguez, 1968). The optimum size is essentially a compromise between two opposing factors. On the one hand the necessity to have the bag large enough relative to the sample size used, so as to ensure that rumen fluid can easily enter the bag and mix with the sample. On the other hand there is the necessity to have a bag small enough to be easily withdrawn through the rumen cannula. The ratio of width to length of the bags should be between 1:1 (i.e. square) and 1:1.25. Standard recommend bag sizes used today are 5 cm x 5 cm and 5 cm x 10 cm. The bottom corners should be rounded so as to prevent any of the sample being trapped, and the bag can be closed either by tying or with a simple draw string (Ørskov *et al*., 1980).

2.7.4.2. Pore size of the bag material

The ideal pore size shall allow the entrance of rumen liquor and micro-organisms i.e. protozoa, bacteria and fungi and the efflux of degraded fraction and accumulated gases. When the gas does not escape, the bags may float on top of the solid phase of the rumen and give very variable results. Bag pores should also be sufficiently small to minimize losses of undegraded feed particles, while maintaining an active microbial population and also preventing blockages of the pores by feed components. The choice of bag porosity must thus be a compromise between loss of undegraded feed particles and the movement of micro-organisms through the bag. A pore size between 40-60µm is adopted as a standard (Ørskov, 1992).

The efflux of feed particles from the bags without breakdown by rumen micro-organisms is corrected for by using zero-hour bags. These bags are filled with the substrate but are not incubated in the rumen. They are washed and dried in the same way as the incubated bags. Furthermore, the zero-hour bags are used to correct for passage of material from pressure applied to the nylon bags during washing.

2.7.4.3. Sample size to bag surface ratio

The ideal ratio has been quoted as about 15mg DM/cm^2 (Ørskov, 1992; Michalet-Doreau & Ould-Bah, 1992). With the size of the bags suggested, samples of between 3 and 5g of DM are appropriate. For smaller bags, the quantity should be less, but with a minimum of 2g DM. The incubated sample should be able to move freely within the bags to avoid formation of microenvironments that affect replication of the analysis. A reduction in degradability was observed by many workers as sample size, for a given bag size, was increased (Tomlin *et al.*, 1967; Mehrez & Ørskov, 1977). The smallest amount of sample necessary may be defined as that which will provide adequate amount of residue required for further analysis after incubation.

2.7.4.4. Number of bags incubated

The number of bags at one given time should depend on the species of the host animal (Ørskov *et al.*, 1980). In cattle which generally can have much larger rumen cannulae than sheep, the number of bags incubated at one time can be greater than with sheep and have been quoted at 12 and 20 by Balch & Johnson, (1950) and Miles, (1951) respectively. With sheep, Mehrez & Ørskov, 1977) found it preferable to incubate no more than five bags in the rumen. Since most of the cannulae are now 40 mm internal diameter, nine bags can now be used in sheep. The major constraint is the removal of the bags from the rumen, and not interaction between bags within the rumen. The tendency of the bags to clump together can be minimised by introducing the bags individually and slightly varying the length of string allowed free, or by tying the bags in a line (Ørskov *et al.*, 1980).

2.7.4.5. Time of incubation in the rumen

Much of the published data relate to experiments in which the researchers tended to incubate bags for only a few different times, and attempted to relate dry matter losses from the bags to the apparent digestibility of the feedstuff. The emphasis is now on measuring the rate of degradation, which requires a number of measurements of the degradation after different times. The total time for complete degradation will vary with the characteristics of the material being incubated, and hence the intermediate times chosen will also vary from 6 to 120 hours. As a rough guide: concentrates require 12-36 hours, good quality forages 24-60 hours and poor quality forages 48-72 hours. Ørskov *et al.*, (1980) states that these are times required to reach, or nearly reach, the asymptote (potential degradation).

2.7.4.6. Positioning of the bags in the rumen

Balch & Johnson, (1950) reported that a more rapid digestion was obtained when the bags were incubated in the ventral rumen sac of cattle, though later work by Erwin & Elliston (1959) and Rodriguez (1968) showed that the position of bags in the rumen had little or no effect on the degradation of the various feeds. No reduction in the variability in the DM disappearance between bags has been shown by attaching weights so as to anchor the bags in the ventral sac of the rumen, but Rodriguez (1968) found that variation between bags was reduced when the bags were attached to 50 cm of string rather than to 30 cm. He suggested that the longer string allowed greater movement of the bags within the rumen of the steer, and thus minimised the effects of variations in the rumen environment.

2.7.4.7. Replication of measurements

The important source of variation is between the animals (Mehrez & Ørskov, 1977). To measure degradabilities of dry matter and protein, at least 3 animals are needed per treatment.

2.7.4.8. Washing of the bags

In order to eliminate other feed particles and micro-organisms from the bag after incubation, it can be washed by hand or machine (Michalet-Doreau & Ould-Bah, 1992). The residue is dried to determine the losses during incubation time. Feed samples should be placed in more than two different bags, and then washed in the same way in order to determine the washing losses. Such analysis should provide information on the presence of very fine particles and/or rapidly degradable fraction in the sample.

2.8. Interpretation of *in sacco* results

It is assumed that sample disappearance is synonymous with degradation (Karlsson *et al*., 2009). Although this is generally true, there are several cases where the assumption is not valid, for example, substrates with a fast disappearance rate or water soluble material (Ørskov, 1992). The degradation curve should plot the sample degradation against time. The curve may be expressed mathematically using the equation proposed by Ørskov & McDonald (1979):

$$P = a + b(1 - e^{-ct})$$

Where p is the percentage degradation with time *t*; *a* is the soluble fraction; *b* is the insoluble but potentially degradable fraction. The $a + b$ value is the potential degradability of the material, all expressed in percentage, and *c* is the degradation rate, expressed in percent/hour. The extent of dry matter and protein breakdown will depend upon the time for with the feed sample remains in the rumen. Ørskov & McDonald (1979) pointed that the effective degradability P may be defined as follows:

$$\mathrm{P} = a + \left[\frac{bc}{\mathrm{c} + r}\right][1 - e^{-(c+r)t})$$

Where, r is the rate of passage from the rumen to the abomasum. As the time of incubation increases, the fraction of the protein remaining in the rumen falls to zero, as does the rate of breakdown, and P may be defined as follows:

$$\mathrm{P} = a + bc/(c + r)$$

In this equation *a* is the immediately degraded protein, and $bc/(c + r)$ the slowly degradable fraction. The value of r may be determined by the treatment of protein with dicromite. The *a*, *b* and *c* values are used to determine the feed potential of forages as well as to recommend feeding strategies. Feed potential indicates the consumption of digestible energy relative to maintenance.

2.9. Summary

The objectives of the study were to compare diurnal changes in feeding behaviour and plant species selection of the Tswana and Boer goats (variation within and between breeds) during the cold-dry season and the hot-wet season, to compare the nutritive values of feeds selected by the Tswana and Boer goat during the cold-dry season and the hot-wet season and to determine the rate of ruminal degradability of the three most preferred bush species selected by the Tswana and Boer goats during the cold-dry season and the hot-wet season using *in sacco* digestion. Experiments were designed to test the hypotheses by comparing free ranging Tswana and Boer goats in the hot-wet season and the cold-dry season using many of the techniques described above. The area chosen to study the goats was the Eastern Cape Province where a complete study of the vegetation was first completed. Feed selection, species composition and the behaviour of the goats was intensively studied over a period of a year. An analysis of all the factors affecting plant selection was also completed. The nutritive value of certain plants and their potential degradability was studied in order to gain further insight into seasonal variations in plant selection and possible management implications.

CHAPTER 3

FACTORS AFFECTING THE FEEDING BEHAVIOUR OF FREE RANGING TSWANA AND BOER GOATS

3.1. Introduction

The goat's ability to utilize sparse vegetation and survive in stressful nutritional environments better than other ruminant species (Silanikove, 2000; Lachica & Aguilera, 2003; Iniguez, 2004) makes this species an appropriate candidate as a food producing animal in arid environments (Mellado *et al*., 2004). Goats have certain physical characteristics such as narrow muzzle, mobile upper lip, prehensile tongue, bipedal stance, agility in climbing and physical dexterity that provide them with necessary foraging skills to select preferred plant species (Taylor & Kothman, 1990; Ngwa *et al*., 2000; Mellado *et al*., 2004) and adapt to different food resources according to its availability (Orihuela & Solano, 1999).

Goats are mainly raised in rangelands in semi-deserts and sub-tropic conditions (Devendra, 1990; Keskin *et al*., 2005; Tefera *et al*., 2008: Salem *et al*., 2010). Conditions in the rangelands, such as heterogeneity, as well as the seasonal changes of potential feeds and nutritional restrictions, induce range ruminants to exhibit strong food selectivity in order to meet the demands for maintenance and production (Senft *et al*., 1987; Agreil & Meuret, 2004; Morand-Fehr *et al*., 2004). The effect of selection by these grazing herbivores changes the species of plants found in various populations, but the mechanism underlying feeding behaviour and diet selection by goats remains poorly understood (Illius *et al.*, 1999). Interaction between goat choice rules and plant characteristics trigger consistent and dynamic behavioural adjustments (Agreil & Meuret, 2004). Understanding feeding behaviour and diet selection by ruminants is imperative for efficient rangeland management as well as profitable animal production from rangelands because these parameters affect animal performance and hence production (Ungar, 1996; Torrano & Valderrábano, 2005; Sanon *et al*., 2007).

To achieve acceptable levels of goat performance which are compatible with resource preservation, a deep understanding of feeding behaviour and diet selection is needed (Sanon *et* *al*., 2007). Efficient utilization of available resources also requires information on plant density, forage species and phytomass at any specific site to define its carrying capacity and strategies of feed supplementation according to desired level of production (Lachica & Aguilera, 2003; Yayota *et al*., 2009).

The objective of the study was to determine how the season, time of the day and period of occupation of a camp influence the feeding behaviour and plant species selection of Tswana and Boer goats.

3.2. Materials and Methods

3.2.1. Study site

The research was conducted at the University of Fort Hare Research Farm near Alice, in the Eastern Cape Province of South Africa ($32^0$49'S, $26^0$54'E). The research farm is situated 80km inland from the Eastern Cape coastline at an altitude of 500-600 m above sea level. This project was part of a collaborative study between the Department of Anatomy and Physiology, University of Pretoria and the Department of Livestock and Pasture Science, University of Fort Hare. All procedures used in experiments received prior approval from the University of Pretoria research committee.

3.2.2. Vegetation

The vegetation is representative of Acocks (1975) "False Thornveld of the Eastern Cape" and ranges from grassland through *Acacia karroo* Savannah to dense, clumped, medium short evergreen thicket. The Savannah consists of subtropical thicket vegetation, mainly dominated by deciduous woody shrubs shorter than 1.5m, although the woody layer reaches 4 to 5m (Scogings *et al*., 1996).

Prior to the start of the experiment in each season (cold-dry season and hot-wet season), a botanical survey was done for each plot according to the method described by Trollope (1986).

In addition, a disc pasture meter (Bransby & Tainton, 1977) was used to estimate the phytomass of grass at the beginning and end of the experiments as shown in Tables 3.1, 3.2, 3.3 and 3.4.

Table 3.1. Veld condition assessment score - Grass component (points 10000 m^2)

GRASS SPECIES	COLD-DRY SEASON	HOT-WET SEASON
	%	%
DECREASERS		
Panicum maximum	5	
Panicum stapfianum		1
Themeda triandra	13	41
INCREASERS		
Aristida congesta	1	
Cymbopogon plurinodis	14	12
Cynodon dactylon	5	
Digitaria eriantha	43	18
Eragrostis chloromelas	3	1
Eragrostis curvula	5	4
Forbs	2	1
Microchlora caffra	1	
Sporobolus africanus	7	5
Sporobolus fimbriatus		17
INVADERS		
Paspalum dilatatum	1	
VELD CONDITION SCORE	452 (63.3%)	676 (94.7%)
GRASS PHYTOMASS	3.6 ton/ha	3.6 ton/ha
GRAZING CAPACITY	4.7 ha/AU	3.2 ha/AU

The vegetation is dominated by four grass species: *Digitaria eriantha* (the cold-dry season 43 %; hot-wet season 18%), *Themeda triandra* (cold-dry season 13 %; the hot-wet season 41 %), *Cymbopogon plurinodis* (cold-dry season 14 %, hot-wet season 12 %) and *Sporobolus fimbriatus* (the hot-wet season 17 %; not available in the cold-dry season). Eight deciduous and semi-deciduous tree and shrub species that are dominant are *Acacia karroo* (cold-dry season 6 %, hot-wet season 18 %), *Coddia rudis* (cold-dry season 21 %, hot-wet season, 17 %), *Maytenus heterophylla* (cold-dry season 7 %, hot-wet season 12 %), *Olea africana* (cold-dry season 5 %, hot-wet season 8 %), *Rhus refracta* (cold-dry season 7 %; not available in the hot-wet season), *Grewia occidentalis* (cold-dry season 5 %, hot-wet season 7 %), *Scutia myrtina* (cold-dry season 5 %, hot-wet season 7 %) and *Lippia javanica* (cold-dry season 31 %, hot-wet season 25 %). Veld condition assessment was 63.3 % for the cold-dry season and 94.7 % for the hot-wet season. Grass phytomass was similar for both the cold-dry season and the hot-wet season (3.6 ton/ha). Bush phytomass was 1299 TE/ha and 5272 TE/ha for the cold-dry season and the hot-wet season, respectively.

Table 3.2. Percentage available, acceptable and unacceptable bush species

BUSH SPECIES	**COLD-DRY SEASON**	**HOT-WET SEASON**
Acceptable species	**(%)**	**(%)**
Acacia karroo	6	18
Coddia rudis	21	17
Cussonia spicata	0.3	
Ehretia rigida	3	1
Grewia occidentalis	5	7
Lippia javanica	31	25
Maytenus heterophylla	7	12
Olea Africana	5	8
Rhus longispina	0.3	
Rhus undulate		1
Rhus lucida	2	1
Rhus macawana	0.3	
Rhus refracta	7	
Scutia myrtina	5	7
Unacceptable species		
Diospyros lyciodes	2	6
Lantana camara	0.3	
Leucas capensis	1	1
Lyceum ferocissimum	1	

Table 3.3. Bush component – Tree Equivalents/ha, browsing units/ha and stocking rate (ha/SSU)

	COLD-DRY SEASON	**HOT-WET SEASON**
Tree equivalent (bush phytomass) **per ha:** current	1299 TE/ha	5273 TE/ha
Browsing units		
per ha: current	1266 BU/ha	525 BU/ha
potential	1291 BU/ha	525 BU/ha
Stocking rate = browsing capacity		
ha/SSU: current	1.6 ha/SSU	3.8 ha/SSU
potential	1.6 ha/SSU	3.8 ha/SSU
ha/AU :	0.3 ha/AU	0.6 ha/AU

AU (animal unit) = a mature livestock unit weighing 450 kg (Danckwerts, 1979)
SSU (small stock unit) = one sixth of an AU
(TE) Tree equivalents = the total phytomass of bush and are expressed as the number of bushes 1.5m high.
Current browsing units = the number of acceptable and available trees and shrubs that are 1.5 m high have browse within the 0-1.5 m stratum
Potential browsing units = acceptable, available and unavailable trees and shrubs where it is assumed that the unavailable bushes are reduced in height to 1.5 m, thus causing them to coppice and shoot before making them available to goats.
Stocking rate is equivalent to the browsing capacity of bush if the utilization of grass is to be kept to a minimum.

Table 3.4. Number and percentage of available bush species that are acceptable and those that are unacceptable

BUSH SPECIES	**COLD-DRY SEASON**	**HOT-WET SEASON**
Available/acceptable		
No :	3987	3500
% :	95.0	92.1
Available/unacceptable		
No :	200	300
% :	5.0	7.9
TOTAL	4187	3800

3.2.3. Soil type

The predominant soil forms in the False Thornveld of the Eastern Cape are Glenrosa and Mispah. These have shallow top soils and hence low plant-available water storage capacities. Since most of the soils are derived from shales and sandstones of the Beaufort and Ecca series, they have high silt and fine sand contents, which result in very poor infiltration capacities thus resulting in low plant available water storage. Although low in phosphates, these soils are moderately fertile (Hensley & Laker, 1979: Teague & Walker, 1988).

3.2.4. Climate and rainfall

The mean daily temperature ranges from 18-21 ^{o}C in the hot-wet season and 10-13 ^{o}C in the cold-dry season (Teague & Walker, 1988). Mean monthly temperatures during the study year ranged from 11.5 to 22.2 ^{o}C. The mean maximum temperatures for the cold-dry season and the hot-wet season (2007) were 21 and 24 ^{o}C, respectively, while the mean minimum temperatures for the cold-dry season and the hot-wet season were 6 and 13 ^{o}C, respectively. Frost is common during July and August. Owing to the frost and low rainfall during the dry season, late cold-dry season and early spring (May-October) may be considered to be the more critical period with regard to foraging. The climate can be regarded as semi-arid with a mean annual rainfall of 574 mm and which varies between 227 mm and 967 mm. The rainfall pattern is bimodial with a distinct peak in March and a lesser one in October. The average annual rainfall during the study year (2007) was 506.4 mm. Most of the rain (79 %) fell during the seven months of the hot-wet season from October to April and the cold-dry season (21 %) was relatively dry. Climatic data were obtained from Honeydale research farm records as obtainable from the South African Weather Bureau. The rainfall and temperature patterns during the research period are shown in Fig. 3.1 and 3.2, respectively.

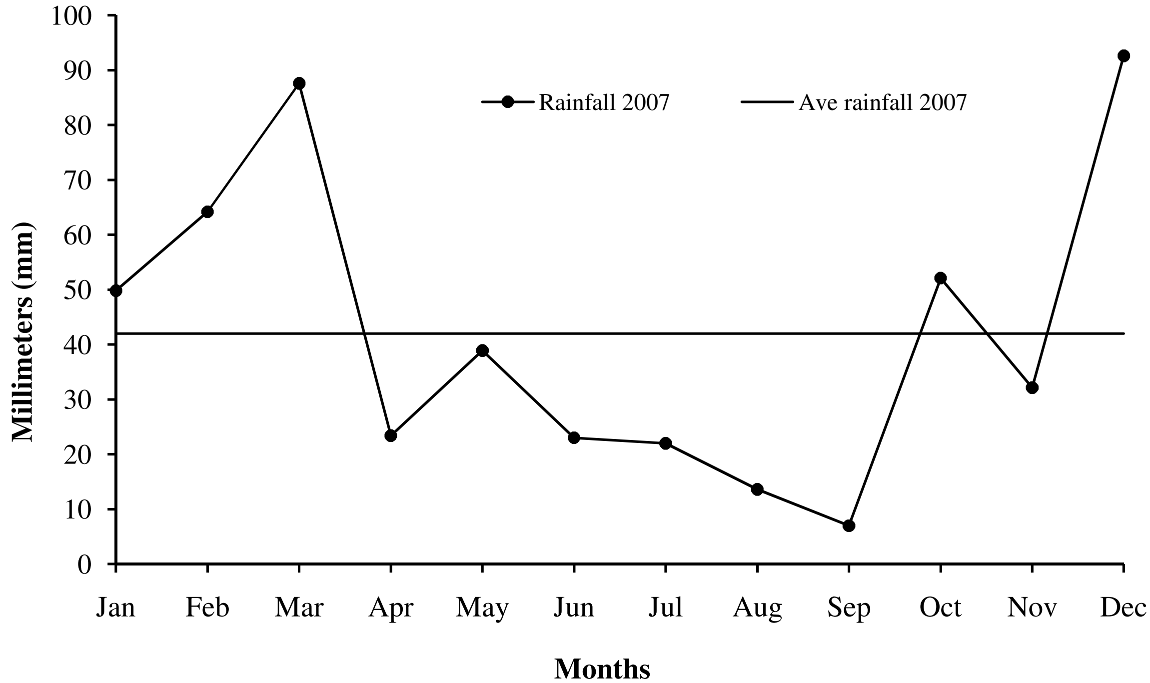

Figure 3.1. Rainfall pattern during the 2007 research period

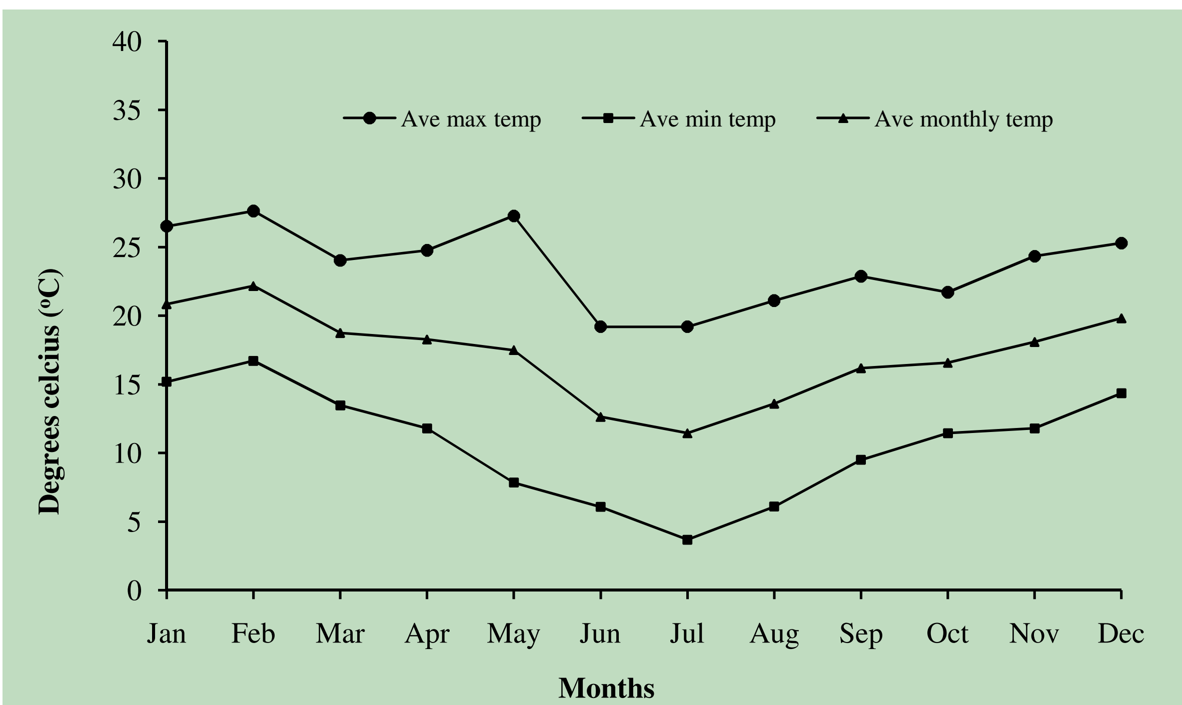

Figure 3.2. Temperature pattern during the 2007 research period

3.2.5. Experimental animals

The sixteen experimental animals (8 Tswana and 8 Boer goat does) were purchased in November 2005 from Mafikeng area in the North West Province, as this is where the drive for the research originated. The Tswana goats were purchased from Kabe village (about 60 km) west of Mafikeng while the Boer goats were purchased from Lehurutshe village (about 70 km) east of Mafikeng. Both breeds were raised extensively.

The Department of Anatomy and Physiology transported the animals from Mafikeng to Pretoria University following proper and recommended regulations on the transportation of animals. Animals were quarantined for a month and subjected to normal health and disease prevention programs as required by the Department of Anatomy and Physiology research management programmes. The 16 goats were kept on conventional grazing, supplemented with Lucerne/tef hay feeding at the Physiology holding pens in University of Pretoria.

Operations to insert oesophageal and rumen fistulae were performed at the Onderstepoort Veterinary Academic Hospital using standard veterinary surgical procedures. The most recent adaptations to the oesophageal fistulae were used during the trials (Booyse *et al*., 2009). The hospital monitored the post-operative recovery and emergency care of the goats. The researcher and technicians from the department of Anatomy and Physiology were responsible for the routine daily care of the animals.

Three months prior to the start of the research, the 16 does (8 Tswana and 8 Boer goats) were classified on the basis of their feeding behaviour. Goats were observed during a three-hour period at five minute intervals for four days. They were classified as browsers, grazers or intermediate feeders according to the times spent on different feeding activities. The browse: graze ratio, hind legs (bi-pedal stance) and consistency during the four observation days were taken into account during the selection process. The five Tswana and five Boer goats selected were all predominately intermediate feeders and were then operated on to place the oesophageal cannulae according to the methods described by Raats *et al*. (1993). The remaining six goats (3 Tswana and 3 Boer) were rumen cannulated and used for *in sacco* digestion.

After recovery from the operations, goats were transported to Fort Hare University following proper and recommended regulations on the transportation of animals. Animals were quarantined for a month and subjected to normal health and disease prevention programs as required by the Department of Livestock and Pasture Science research management programmes.

3.2.6. Experimental area

Two paddocks (8-9 ha in size) which form part of a wagon wheel system, were rested for at least one growing season prior to the start of the experiment. In each paddock an area of 1ha chosen on the basis of a good balance of bush and grass, and judged to be uniform in terms of vegetation was enclosed. A temporary goat proof fence was used to confine goats to a plot during each of the four-week experimental periods. Each plot had its own water trough and a handling kraal for holding the goats at the entrance of each plot. During both the cold-dry season and hot-wet season, a 1ha plot classified as the False Thornveld of the Eastern Cape (Acocks, 1975) was stocked with 8 Tswana and 8 Boer (mean weight of about 37 kg and about 2 years of age) for a period of four weeks. Five Tswana and five Boer goats were oesophageal fistulated while three Tswana and three Boer goats were rumen cannulated.

3.2.7. Management of animals and collection of data

At the start of each trial, there was an adaptation period of two weeks on the veld immediately adjacent to the experimental area. Five days prior to the start of each of the experiments, goats with oesophageal fistulae were trained with harnesses to acquaint the animals with the handling procedures. The fistulated goats were trained with great care, so that they showed no signs of abnormal behaviour, stress or discomfort during sampling and allowed the operators to approach and handle them in the open without resistance. For easier identification from a distance, the six animals to be observed were painted on both flanks with unique identification numbers (± 300 mm in size). During the three-week experimental periods, the goats had access to the experimental plots during the day (0700h to 1600h) only, but were kraaled at night for safety and supplied with a commercial lick (block). Adjacent paddocks with similar vegetation were used for grazing experimental animals during the interim period between experiments.

3.2.8. Experimental procedures

Twice a week (Tuesdays and Thursdays), during each of the two experimental seasons, feeding behaviour of six goats (3 Tswana, three 3 Boer) was observed. Feeding behaviour observations were recorded from 0800h to 0935h (assumed to represent morning), 1100h to 1235h (assumed to represent midday) and 1400h to 1535h (assumed to represent afternoon goat activity). As there were only three observers, only three goats could be observed at a time. Observers were randomly allocated to goat to avoid human bias. Therefore, from 800h to 0815h, the feeding behaviour of three goats (e.g. 3 Tswana) was observed followed by the observations of the 3 Boer goats from 0821h to 0835h. Observations continued at 0900h to 0915h with 3 Boer goats followed by 3 Tswana at (0921h-0935h). On each day of observation, the three goats (representing a particular breed) to start the observation with, were selected randomly. There was a five minutes break in between the observation periods to allow each observer to collect the oesophageal extrusa sample for the determination of the nutrient content of the diet as selected by free ranging goats, from each goat under observation. The same procedure was repeated during midday (1100h-1235h) and afternoon (1400h-1535h) observations. During observations, the following activities of the goats were recorded: browsing, grazing and non-feeding activities (walking, lying, standing and drinking). Browsing activity included bi-pedal stance (recorded separately) and represented the browsing of all woody species. Tree/Bush species browsed at the time of recording were visually identified and recorded separately. Grazing activity represented the grazing of grasses without the identification or recording of species. Non-feeding activities included separate recordings of walking, standing, lying and drinking. Each goat was observed for 30 minutes in the morning, midday and afternoon observation periods.

3.3. Statistical analysis

During the 30 minute observation time, the time spent on different activities (grazing, browsing, walking, drinking, lying and standing) by a goat was recorded in minutes and later converted into percentages. The percentage time was arcsine transformed prior to subjecting the data to analysis of variance. The analysis of data was conducted using Generalized Linear Model Procedure of SAS (SAS, 2003). The significance of a factor on a given feeding behaviour was tested at P=0.05. The Tukey procedure was used to separate means among levels within a significant factor. The means were back transformed into percentage for the reporting purpose. The factors defined in the analysis model were breed, days in the grazing camp, time of the day, season and two and three way interactions among these factors. In all activities three-way interactions were not significant and not included in the final analysis.

The following statistical model was used on each of the activities:

$$Y = \mu + B_i + T_j + D_k + S_l + (BT)_{ij} + (BD)_{ik} + (BS)_{il} + (TD)_{jk} + (TS)_{jl} + (DS)_{kl} + \text{error}$$

Where

Y = Observation on any of the feeding activities,

μ = Overall mean,

Bi = Breed effect (Indigenous Tswana vs Boar goat),

Tj = Time of the day effect**:** Morning (0800h-0935h), midday (1100h-1235h) and afternoon (1400h-1535h),

Dk = Day in camp effect (1^{st} day to 6^{th} day)

S = Season effect (cold-dry season vs hot-wet season)

(BT)jj to (DS)kl = Two way interaction effects among the factors

e = random error term, assumed to be distributed with mean of 0 and variance, σ^2_e

3.4. Results

Proportions of time spent on feeding and non-feeding activities by goats across seasons are presented in Table 3.5. On average, the goats in this study were observed to spend 21.9 %, 44.7% and 33.3% of their day on browsing, grazing and non-feeding activities (walking, standing, lying, drinking). This implies that goats spent 33 % and 67 % of their active feeding time browsing and grazing respectively.

Table 3.5 Percent of time (least square means) spent on browsing, grazing and non-feeding activity in goats

Behavioral activities	Least square mean (%)
Browsing	21.9 [a]
Grazing	44.7 [b]
NFA	33.3 [c]

Means in the same column with different superscripts are significantly different (P < 0.05). The SE = 0.88

3.4.1. Factors affecting time spent on browsing

The breed, season, time of the day and period of occupation of a camp significantly (P<0.05) influenced the relative time the goats devoted to browsing as shown in Table 3.6. The average percentage time spent on browsing was significantly higher in the cold-dry season (21.7 ± 0.04) compared to the hot-wet season (16.7 ± 0.04).

Table 3.6. Percentage time (least square means) spent browsing as influenced by season, breed, time of the day and period of occupation of a camp by goats

Factors	Browsing time (%)	SE
Season		
The cold-dry season	21.7[a]	0.04
The hot-wet season	16.7[b]	0.04
Breed		
Tswana	23.5[a]	0.04
Boer	15.1[b]	0.04
Time of the day		
(0800h – 0935h)	24.3[a]	0.06
(1100h – 1235h)	15.9[b]	0.06
(1400h – 1535h)	17.6[b]	0.06
Period of occupation		
Day 1	28.5[a]	0.11
Day 2	19.3[ab]	0.11
Day 3	22.6[ab]	0.11
Day 4	16.5[b]	0.11
Day 5	15.4[b]	0.11
Day 6	13.9[b]	0.11

Means in the same column with different superscripts are significantly different (P < 0.05).

Across seasons, Tswana goats allocated more time to browsing (23.5 ± 0.04) than the Boer goats (15.1 ± 0.04). This difference in browsing time was highly significant (P=0.0001). Time spent on browsing by goats changed significantly during the different times of the day (P= 0.005). On average across times of the day, goats spend more time on browsing in the morning (24.3 ± 0.06) compared to midday (15.9 ± 0.06) and afternoon (17.6 ± 0.06). There were significant differences (P=0.002) in time spent on browsing during the period of occupation of the grazing camp.

Tswana goats showed significant seasonal variation in browsing time (30.0 in the cold-dry season vs 17.7 in the hot-wet season – breed by season interaction), while the browsing time of Boer goats did not show this seasonal difference (Table 3.7).

Table 3.7 Percentage time (least square means) spent browsing as influenced by season, breed, time and period of occupation of a camp in Tswana and Boer goats

Factors	**Browsing time (%)**		**SE**
	Breed		
	Tswana	**Boer**	
Season			
The cold-dry season	30.0 ^{a}	14.4 ^{b}	0.07
The hot-wet season	17.7^{b}	15.7 ^{b}	0.07
Time of the day			
(0800h – 0935h)	31.4	17.8	0.11
(1100h – 1235h)	17.0	14.8	0.11
(1400h – 1535h)	23.0	12.8	0.11
Period of occupation			
Day 1	33.6	23.5	0.22
Day 2	25.2	14.0	0.22
Day 3	23.3	21.9	0.22
Day 4	22.6	11.1	0.22
Day 5	22.1	9.7	0.22
Day 6	15.6	12.2	0.22

Means in the same row with different superscripts are significantly different (P < 0.05).

Although Tswana goats spent more time browsing both in the morning and afternoon compared to Boer goats, there was no significant differences (P>0.05) between the breeds. The number of days spent occupying a camp did not differ significantly (P>0.05) between the Tswana and the Boer goats but browsing seemed to decrease with advancing period of occupation.

The time the goats spent browsing was not affected by the time of day (Table 3.8) during either the cold-dry season or the hot-wet season. However, the amount of time the goats spent browsing in the camp on progressive days became significantly different (P=0.01) as the period of occupation increased in the cold-dry season.

Goats spent more time browsing during the early days of occupation of a camp. With advancing period of occupation during the cold-dry season, goats decreased their browsing time from 33.3 % on the first day of observations to 11.7 % on the last day of the observations. Similarly during the hot-wet season, browsing decreased with advancing period of occupation of a camp from 23.9 % on the first day of sampling to 16.2 % on the last day of sampling. The decrease in time spent browsing with advancing period of occupation was high during the cold-dry season (21 %) compared to the hot-wet season (8 %).

Table 3.8. Percentage time (least square means) spent browsing during the cold-dry season and the hot-wet season as influenced by time and period of occupation of a camp by goats

Factors	**Browsing time (%)**		**SE**
	Season		
	The cold-dry season	**The hot-wet season**	
Time of the day			
(0800h – 0935h)	25.9	2.7	0.10
(1100h – 1235h)	17.8	14.0	0.10
(1400h – 1535h)	21.6	53.8	0.10
Period of occupation			
Day 1	33.3[a]	23.9[a]	0.21
Day 2	25.0[a]	14.2[a]	0.21
Day 3	31.6[a]	14.7[a]	0.21
Day 4	19.8[a]	13.4[a]	0.21
Day 5	12.5[b]	18.5[a]	0.21
Day 6	11.7[b]	16.2[a]	0.21

Means in the same column with different superscripts are significantly different (P < 0.05).

The time of the day on the consecutive days of observation in the camp showed no significant effect (P>0.05) on the time goats spent browsing. However, results show an interesting trend in time spent browsing during the different time slots (Figure 3.3).

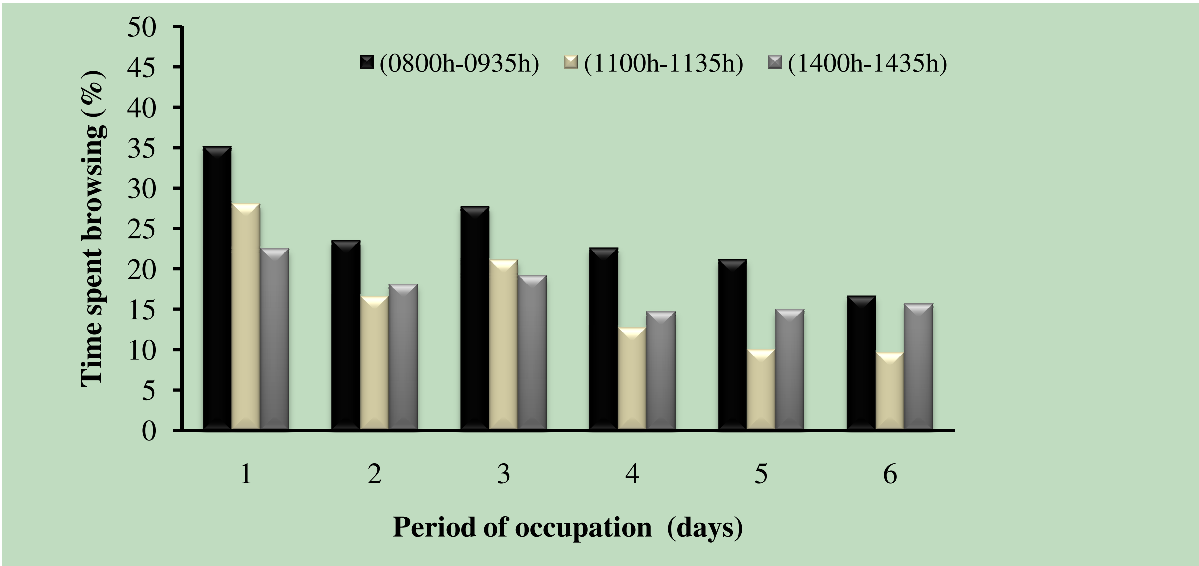

Figure 3.3. The browsing trend of goats as influenced by time of the day and period of occupation

During each of the six observation days, browsing was high in the morning compared to midday and afternoon feeding periods. Browsing showed a decreasing trend with advancing period of occupation in the morning, at midday and in the afternoon.

3.4.2. Factors affecting time spent on grazing

There is a significant difference between seasons ($P<0.0001$) and breeds ($P=0.01$) in terms of the amount of time spent on grazing. However, time of the day and period of occupation of a camp did not significantly ($P>0.05$) influence the amount of time the goats spent grazing. The average time spent on grazing by goats was significantly higher ($P=0.04$) in the hot-wet season (59.3 ± 0.04) compared to the cold-dry season (26.8 ± 0.04) as shown in Table 3.9.

Table 3.9 Percentage time (least square means) spent grazing as influenced by season breed, time and period of occupation of a camp by goats

Factors	Grazing time (%)	SE
Season		
The cold-dry season	26.8^{a}	0.04
The hot-wet season	59.1^{b}	0.04
Breed		
Tswana	39.0^{a}	0.04
Boer	46.3^{b}	0.04
Time of the day		
(0800h – 0935h)	41.9	0.07
(1100h – 1235h)	38.9	0.07
(1400h – 1535h)	47.1	0.07
Period of occupation		
Day 1	35.6	0.12
Day 2	45.1	0.12
Day 3	48.2	0.12
Day 4	45.1	0.12
Day 5	41.6	0.12
Day 6	40.3	0.12

Means in the same column with different superscripts are significantly different ($P < 0.05$).

In general, Boer goats allocated more time to grazing (46.3 ± 0.04) compared to Tswana goats (39.0 ± 0.04). This difference in grazing time between the two breeds was highly significant ($P=0.01$). There was no significant difference ($P>0.05$) in time goats spent grazing both during the different times of the day and during the period of occupation of a grazing camp ($P>0.05$).

The Tswana and Boer goats did not differ ($P>0.005$) in the amount of time spent grazing during either the cold-dry season or the hot-wet season as shown in Table 3.10. The amount of time spent grazing at different times of the day did not differ significantly ($P>0.005$) between breeds, although goats spent more time grazing during the afternoon (Tswana 42.8: Boer 51.6 ± 0.12) compared to morning (Tswana 37.1: Boer 46.8 ± 0.12) and midday (Tswana 37.2: Boer 40.6 ± 0.12). During the first days of occupying a camp, the Boer goats spent significantly more ($P=0.01$) time grazing than the Tswana goats.

Table 3.10 Percentage time (least square means) spent grazing as influenced by season time and period of occupation of a camp by Tswana and Boer goats

Factors	**Grazing time (%)**			
	Tswana	**SE**	**Boer**	**SE**
Season				
The cold-dry season	24.7	0.07	28.9	0.09
The hot-wet season	54.4	0.07	64.1	0.09
Time of the day				
(0800h – 0935h)	37.1	0.12	46.8	0.13
(1100h – 1235h)	37.2	0.12	40.6	0.13
(1400h – 1535h)	42.8	0.12	51.6	0.13
Period of occupation				
Day 1	31.9	0.27	39.4	0.27
Day 2	32.8[a]	0.27	57.8[b]	0.27
Day 3	42.5	0.27	53.8	0.27
Day 4	38.1	0.27	52.1	0.27
Day 5	45.6	0.27	37.6	0.27
Day 6	43.6	0.27	37.1	0.27

Means in the same row with different superscripts are significantly different ($P < 0.05$).

The time goats spent grazing at a particular time of day was not affected ($P>0.05$) by the season when the observations were done (Table 3.11). The highest percentage grazing time was recorded during the hot-wet season in the afternoon (61.8 ± 0.12) while the lowest percentage grazing time was recorded in the cold-dry season during midday (20.1 ± 0.12).

After day 1 the effect of the period of occupation of the camp on the amount of time spent grazing was significantly different ($P=0.04$) between the hot-wet season and the cold-dry season. Goats spent less time grazing during the early days of occupation of a camp during the hot-wet season. With advancing period of occupation, goats increased their grazing time from 43.9 % on the first day of observations to 62.4 % on the last day of the observations. However, during the cold-dry season, grazing decreased with advancing period of occupation of a camp from 27.7 % on the first day of sampling to 20.1 % on the last day of sampling.

Table 3.11. Percentage time (least square means) spent grazing during the cold-dry season and the hot-wet season as influenced by time of the day and period of occupation of a camp by goats

Factors	**Grazing time (%)**		
	Cold-dry season	**Hot-wet Season**	**SE**
Time of the day			
(0800h – 0935h)	28.0	56.5	0.13
(1100h – 1235h)	20.1	59.5	0.13
(1400h – 1535h)	32.7	61.8	0.13
Period of occupation			
Day 1	27.7	43.9	0.27
Day 2	29.0	61.8	0.27
Day 3	35.8	60.7	0.27
Day 4	28.8	61.9	0.27
Day 5	20.2	64.8	0.27
Day 6	20.1	62.4	0.27

Means in the same column with different superscripts are significantly different (P < 0.05).

3.4.3. Factors affecting time spent on non-feeding activities

The breed and period of occupation of a camp did not significantly influence the relative time goats devoted to NFA (P>0.05). However, season (P<0.0001) and time of the day (P=0.004) significantly influenced the time goats spent on NFA as shown in Table 3.12.

Table 3.12 Percentage time (least square means) spent on NFA as influenced by season, breed, time of the day and period of occupation of a camp by goats

Factors	Time spent on NFA (%)	SE
Season		
The cold-dry season	68.8 [a]	0.07
The hot-wet season	31.9 [b]	0.07
Breed		
Tswana	51.9	0.07
Boer	48.9	0.07
Time of the day		
(0800h – 0935h)	45.0 [a]	0.11
(1100h – 1235h)	59.4 [b]	0.11
(1400h – 1535h)	46.7 [a]	0.11
Period of occupation		
Day 1	50.2	0.22
Day 2	47.9	0.22
Day 3	40.5	0.22
Day 4	51.0	0.22
Day 5	53.0	0.22
Day 6	59.8	0.22

Means in the same column with different superscripts are significantly different ($P < 0.05$).

On average goats spent more time on NFA during the cold-dry season (68.8 ± 0.07) than the hot-wet season (31.9 ± 0.07). This difference in time spent on NFA was highly significant ($P<0.0001$). Throughout the year the Boer and Tswana goats did not differ significantly ($P>0.05$) in the amount of time allocated to NFA (Tswana 51.9 ± 0.07; Boer 48.9 ± 0.07). Time spent by goats on NFA changed significantly during the day ($P=0.004$). On average, the midday period was dominated by NFA (59.4 ± 0.11) compared to morning (45.0 ± 0.11) and afternoon (46.7 ± 0.11) activities. Goats spent less time on NFA (46.2 ± 0.22) during the early days (first 3 days) of occupation of a camp. However, with advancing period of occupation (last 3 days), time spent on NFA increased (54.6 ± 0.22). There was no significant difference ($P>0.05$) in time spent on NFA during the period of occupation of a camp.

Tswana and Boer goats did not differ significantly ($P=0.05$) in the amount of time allocated to NFA during either the cold-dry season or the hot-wet season as shown in Table 3.13.

Table 3.13 Percentage time (least square means) spent on NFA as influenced by season, time of the day and period of occupation of a camp by Tswana and Boer goats

Factors	Grazing time (%)		SE
	Tswana	**Boer**	
Season			
The cold-dry season	66.7	70.9	0.15
The hot-wet season	37.0	27.0	0.15
Time of the day			
(0800h – 0935h)	43.8	46.2	0.22
(1100h – 1235h)	63.9	54.8	0.22
(1400h – 1535h)	47.9	45.6	0.22
Period of occupation			
Day 1	48.6	51.5	0.44
Day 2	55.4	40.4	0.44
Day 3	48.0	33.3	0.44
Day 4	52.7	49.3	0.44
Day 5	49.3	56.6	0.44
Day 6	57.4	62.2	0.44

Means in the same row with different superscripts are significantly different ($P < 0.05$).

Although Boer goats were observed to spent more time on NFA (70.9 ± 0.15) during the cold-dry season compared to the Tswana goats (66.7 ± 0.15), the difference was not significant ($P>0.05$). In the hot-wet season, time spent on NFA declined for both breeds (Tswana 37.0 ± 0.15; Boer 27.0 ± 0.15) with Tswana goats spending more time on NFA than Boer goats.

Tswana and Boer goats did not differ significantly ($P>0.05$) in the amount of time spent on NFA at different times of the day. Tswana goats spent more time on NFA during midday (63.9 ± 0.22) compared to Boer goats (54.8 ± 0.22). NFA were lower in the morning (Tswana 43.8; Boer goats 46.2 ± 0.22) and afternoon (Tswana 47.9; Boer goats 45.6 ± 0.22) and Tswana goats spent more time on NFA than Boer goats during both these time periods.

The time spent on NFA by the two breeds did not differ significantly ($P>0.05$) over the period of occupation of the camp. It however seems that for both breeds, time spent on NFA increased with advancing period of occupation.

There were no significant differences (P>0.05) between the cold-dry season and the hot-wet season in the time goats spent on NFA during the different times of day, even though it seems more time was allocated to NFA in the cold-dry season compared to the hot-wet season. The highest percentage time spent on NFA was recorded during the cold-dry season at midday (80.3 ± 0.22) while the lowest was recorded in the hot-wet season in the morning (25.3 ± 0.22).

The amount of time the goats spent on NFA during the cold-dry season and the hot-wet season showed significant differences (P<0.0001) the longer the goats were in the camp as shown in Table 3.14. Significant differences were found on days 5 and 6 in both seasons where NFA were very low compared to the other days.

Table 3.14 Percentage time (least square means) spent on NFA during the cold-dry season and the hot-wet season as influenced by time of the day and period of occupation of a camp by goats

Factors	**Time spent on NFA (%)**		**SE**
	Season		
	cold-dry	**hot-wet**	
Time of the day			
(0800h – 0935h)	65.6	25.3	0.22
(1100h – 1235h)	80.3	36.5	0.22
(1400h – 1535h)	59.5	34.2	0.22
Period of occupation			
Day 1	54.1^{a}	46.0^{a}	0.44
Day 2	59.5^{a}	36.4^{a}	0.44
Day 3	49.0^{a}	32.4^{a}	0.44
Day 4	69.4^{a}	32.5^{a}	0.44
Day 5	2.9^{a}	19.7^{b}	0.44
Day 6	5.4^{a}	26.0^{b}	0.44

Means in the same column with different superscripts are significantly different (P < 0.05).

Goats spent more time on NFA during the early days of occupation of a camp. With advancing period of occupation during the hot-wet season, time spent on NFA decreased from 46 % on the first day of observation to 26 % on the last day of observation. During the cold-dry season the amount of time spent on NFA decreased from 54.1 % on the first day of observations to as low as 5.4 % on the last day of observations.

The time goats spent on NFA was not affected by the time of day regardless of the period of time the goats occupied the camp (Figure 3.4)

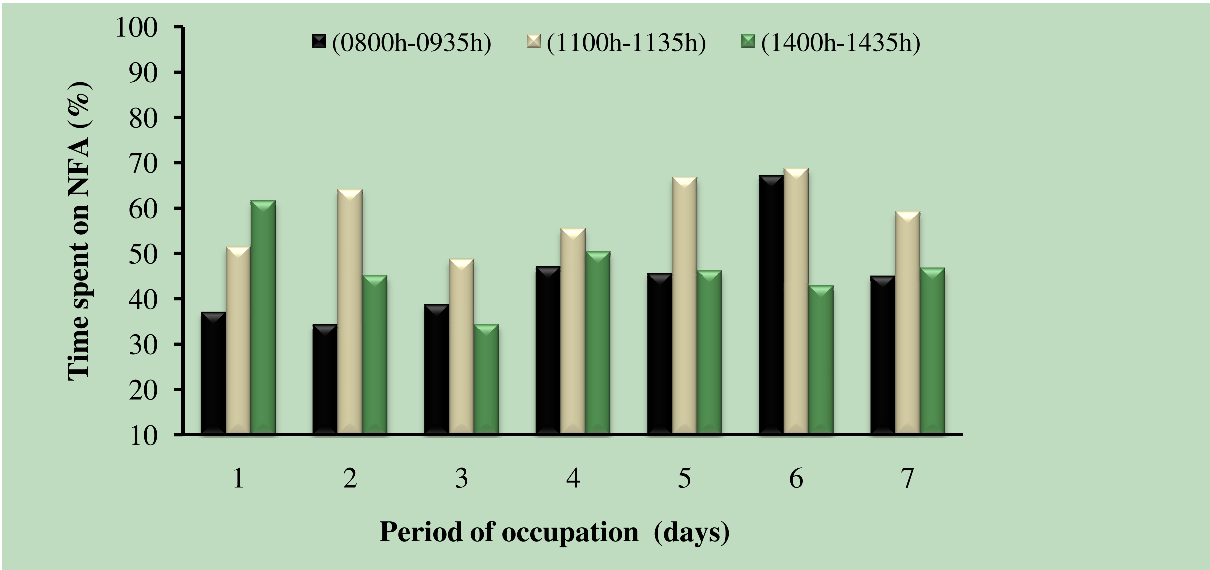

Figure 3.4. Time spent on NFA at different times of the day over the period of occupation

From the graph it seems as though NFA increase with advancing period of occupation in the morning, midday and afternoon.

3.4.4. Factors affecting time spent on walking, standing, lying and drinking by goats

Proportions of time spent by goats on walking, standing, lying and drinking activities across seasons and breeds are presented in Table 3.15. On average, the goats in this study were observed to spend more time walking and standing compared to lying down and drinking.

Table 3.15. Percentage time (least square means) spent walking, standing, lying and drinking by goats

Behavioral activities	Least square mean (%)
Walking	15.6 [a]
Standing	11.6 [b]
Lying	5.8 [c]
Drinking	0.3 [d]

Means in the same column with different superscripts are significantly different ($P < 0.05$). SE = 0.88

The percentage time goats spent walking during the cold-dry season (14.9 %) and the hot-wet season (16.2 %) did not differ significantly (P>0.05). A higher percentage of time (P<0.0001) was spent standing during the cold-dry season (17.6) than the hot-wet season (5.7 %). During the cold-dry season, goats also spent a higher percentage of time (P<0.0001) lying down (10.8 %) compared to the hot-wet season (0.9 %). The percentage time spent drinking was very low (P>0.05) both during the cold-dry season and the hot-wet season (0.5 and 0.1 %) respectively (Table 3.16).

Table 3.16 Percentage time (least square means) spent walking, standing, lying and drinking as influenced by season, breed and time of the day by goats

Factors	**Least square mean (%)**				**SE**
		Activity			
	Walking	**Standing**	**Lying**	**Drinking**	
Season					
Cold-dry	14.9^a	17.6^a	10.8^a	0.9^b	1.24
hot-wet	16.2^a	5.7^b	0.9^b	0.1^a	1.24
Breed					
Boer	16.4^a	9.6^a	7.2^a	0.3^a	1.24
Tswana	14.7^a	13.7^b	4.5^a	0.3^a	1.24
Time of the day					
(0800h–0935h	17.0^a	9.9^a	2.5^a	0.6^a	1.52
(1100h–1235h)	17.7^a	9.8^a	11.3^b	0.1^a	1.52
(1400h–1535h)	12.0^b	15.2^b	3.7^a	0.1^a	1.52

Means in the same column with different superscripts are significantly different (P < 0.05).

The Tswana and Boer goats did not differ significantly (P>0.05) in the time spent walking (Tswana 16.4; Boer 14.7 ± 1.24) or lying down (Tswana 7.2; Boer 4.5 ± 1.24). Boer goats, however, spent a significantly (P=0.02) higher percentage (13.7 ± 1.24) of their feeding time standing compared to Tswana goats (9.6 ± 1.24). The amount of time allocated by goats for drinking was low (0.3 % and 0.3 %) for Tswana and Boer goats respectively (P>0.05). Goats spent more time walking in the morning and midday compared to the afternoon. A significant amount of time was spent standing in the afternoon (15.2 ± 1.52) compared to the morning (9.9 ± 1.52) and midday (9.8 ± 1.52). Time spent lying down was greatest during midday (11.3 ± 1.52) compared to morning (2.5 ± 1.52) and afternoon (3.7 ± 1.52). Time spent drinking was very low during all the different times of the day.

Non-feeding activities of Tswana and Boer goats during the cold-dry season and the hot-wet season are shown in Table 3.17.

Table 3.17 Percent of time (least square means) spent on walking, standing, lying and drinking as influenced by season and breed interaction

Factors	Least square mean (% ± SE)			
			Activity	
	Walking	**Standing**	**Lying**	**Drinking**
Cold-dry				
Tswana	12.8 ± 0.03[a]	10.8 ± 0.07[a]	5.6 ± 0.07[a]	0.03 ± 0.0[a]
Boer	13.6 ± 0.03[a]	18.6 ± 0.07[b]	2.4 ± 0.07[a]	0.04 ± 0.0[a]
Hot-wet				
Tswana	16.97 ± 0.03[a]	3.20 ± 0.07[a]	0.18 ± 0.07[a]	0.004 ± 0.01[a]
Boer	13.58 ± 0.03[a]	2.62 ± 0.07[a]	0.004 ± 0.07[a]	0.004 ± 0.01[a]

Means in the same column with different superscripts are significantly different ($P < 0.05$).

When comparing the Tswana and Boer goats during both the cold-dry season and the hot-wet season there was no difference in time spent walking. It does appear that Tswana goats walked more than the Boer goats in the hot-wet season. During the cold-dry season, Boer goats spent a significantly (P=0.01) higher percentage (18.6 ± 0.07) of their feeding time standing compared to Tswana goats (10.8 ± 0.07). Percentage time spent walking was low in the hot-wet season for both Tswana and Boer goats (P>0.05). Both breeds spent time not differing significantly (P>0.05) lying down in the cold-dry season and the hot-wet season. Percentage time spent lying down was higher in the cold-dry season than the hot-wet season for both breeds with Tswana goats spending more time lying down than the Boer goats. The amount of time allocated by Tswana and Boer goats to drinking was very low both during the cold-dry season and the hot-wet season (P>0.05).

3.5. Discussion

The feeding behaviour of goats is affected by both environmental and animal related factors (Raats & Tainton, 1992; Agreil & Meuret, 2004; Mellado *et al*., 2004). The present study investigated the effect of breed (Tswana and Boer goats), season (the cold-dry season and the hot-wet season), time of the day (diurnal variation), effect of feed availability (period of occupation of a camp) on the feeding behaviour of goats in the False Thornveld of the Eastern Cape.

The effect of season and period of occupation on the feeding behaviour of goats is well documented. Animut & Goetsch (2008), state that season has profound effects on the grazing behaviour of goats. During a year-long study, goats were found to select about 60 % bush, 30 % grass and 10 % forbs (Malecheck & Provenza, 1981). The ratio is however subject to large changes, depending on the prevailing conditions (Raats and Tainton, 1992). Raats (1996a) obtained similar results in the False Thornveld of the Eastern Cape where Boer goats spent on average 61 % and 39 % of their active feeding time browsing and grazing including forbs respectively. Depending on season however, the same study showed that the percentage browse varied from as low as 27 % in June to as high as 86 % in January.

Although goats prefer browse, a variety in browse selection is characteristic of the feeding behaviour of goats (Devendra & Coop 1982; Ramirez *et al*., 1993; Provenza, 1995; Ramírez-Orduña *et al*., 2008; Kumara Mahipala *et al*, 2009). In the present study the proportion of time spent browsing was lower (33 %), and that spent grazing higher (67 %) than the averages found by Malecheck & Provenza (1981) and Raats (1996a). These results are supported by Orihuela & Solano, (1999) and by Odo *et al*, (2001) where Saanen goats were also found to select more grass (63 %) than bush (32 %). The results of the current study, however, contradict those of several authors (Merrill, 1975; Devendra & McLeroy; 1982; Bjelland & Grøva, 1997; Berhane & Eik, 2006; Aharon *et al*., 2007; Yayneshet *et al.*, 2008) where goats were found to prefer browse to grass. This indicates that shifting between browsing and grazing is largely dependent on prevailing conditions (Lu, 1987) such as the amount and distribution of rainfall and the occurrence of frost. In this regard, Bjelland & Grøva (1997) in a study with Boer goats in the False Thornveld of the Eastern Cape, found that time spent browsing during the cold-dry season was substantially higher (52 %) than the 27 % recorded by Raats (1996a). In the present study, time spent browsing in the cold-dry season was also higher (46 %) than that recorded by Raats (1996a) and closer to the 52 % recorded by Bjelland & Grøva (1997) and Sanon *et al*. (2007). During the hot-wet season, bush consumption was substantially lower (24 %) than the 86 % recorded by Raats (1996a).

The changes in time spent browsing (cold-dry season 46 %; hot-wet season 24 %) and grazing (cold-dry season 54 %; hot-wet season 76 %) in this study showed that feed availability, as reflected in the number of days in the camp, had a marked influence on feeding behaviour. This is supported by work done by several researchers (Lu, 1987; Raats & Tainton, 1992; Devendra & McLeroy, 1982; Steel, 1996; Taylor & Kothaman, 1990; Merril & Taylor, 1981) who also found that as the availability of feed decreased more time was spent grazing. Steel (1996) found that season influences browse:graze ratio markedly. Omphile *et al*. (2003) found a contribution of about 80 and 50 % browse in the diets of goats during the dry and wet seasons respectively in an Acacia bush savannah in southeast Botswana. Seasonal variations in browse:graze ratio were also found in Spain and Texas (Devendra & McLeroy, 1982). In the present study, grass consumption was higher in the hot-wet season (76 %) than in the cold-dry season (54 %) while browse consumption was higher in the cold-dry season than in the hot-wet season (46 % and 24 % respectively). These results are supported by Taylor & Kothman (1990) and Odo *et al.* (2001) who found goats to select more grass during the hot-wet season than the cold-dry season. Orihuela & Solano, (1999) states that the major growth of warm season grasses occur during the hot-wet season (rainy season). Schwartz & Ellis (1981) found that season has a major impact on the dietary preference of species and grazing tends to increase during the season when the herb layer is actively growing (Migongo-Bake & Hansen, 1987; El Aich *et al*., 2007; Sanon *et al*., 2007). Actively growing grasses have high digestibility (Codron *et al*., 2007), are succulent and less coarse.

The increase in consumption of browse in the cold-dry season compared to in the hot-wet season is supported by Devendra & McLeroy (1982; Sanon *et al*., 2007) who reported that goats tend to prefer the less coarse grass which is found in the hot-wet season. These workers are of the opinion that browse forms the main source of feed for ruminants in the dry season. This could be attributed to the early and fast growth rate of grasses after the early rain in the hot-wet season, when legumes are still germinating, leaving legumes fresher, less coarse and more succulent at the onset of the dry season. Orihuela & Solano, (1999), state that in early autumn and the cold-dry season, only browse may still be green while the grass dries out. Due to high temperatures and low annual rainfall, lower food availability is a major factor that affects feeding behaviour in dry areas (Abate, 1996). In the present study, goats made a shift in their feeding activity by increasing browse species in their diet when herbaceous species were rare.

Browsing showed a decline with advancing period of occupation both during the cold-dry season and the hot-wet season. Grazing however only showed a decline with advancing period of occupation in the cold-dry season. In the hot-wet season, grazing increased with advancing period of occupation. In this study, the browse:graze ratio showed a clear decline with feed availability both during both the cold-dry season (0.5 to 0.1) and the hot-wet season (0.3 to 0.2). Grass was clearly the preferred feed for goats both in the cold-dry season (54 %) and the hot-wet season (76 %). Browse consumption was higher in the cold-dry season (45 %) and lower in the hot-wet season (24 %). McCammon-Feldman *et al.* (1981), state that the nutritive strategy of goats appears to be to select grass when the protein content and digestibility of the grass is high. However, they switch to browse if the overall nutritive value of browse is high. The initial preference for browse over grass in the cold-dry season during the observation days in this study, suggests the nutritional value of browse was higher than that of grasses, which is expected due to the dormant state of grasses during the cold-dry season. Goats were observed to switch to grazing during the later days of occupation of a camp due to depletion of browse. During the cold-dry season, the decrease in the availability of the most preferred feeds also induced goats to diversify their diets. The botanical composition of the goat's diet varies in accordance with seasonal availability (Animut & Goetsch, 2008) with more species being utilized as the availability decreases. The natural seasonal changes may modify the behaviour patterns of goats (Taylor & Kothman, 1990) affecting proportions of grass or bush consumption according to their availability.

In the present study, the time goats spent walking did not differ significantly between the cold-dry season and the hot-wet season. These results are supported by Ouédraogo-Koné *et al.* (2006)

where goats spent 12.0 % and 10.5 % of their active feeding time walking in the dry and the rainy seasons respectively. The results however do not agree with results from a drier area (Cissé *et al.*, 2002) where animals spent more time walking in the dry season (5 % to 15 %) than in the rainy season (0.6 to 2.6 %). The increased frequency of lying and standing during the dry season was a response to the reduced availability of food items on the range during the dry season. Sharma *et al.* (1998) and Cissé *et al.* (2002) however, found goats to spent more time resting in the hot-wet season than the cold-dry season and speculated that it was probably because of high temperatures that were experienced during the hot-wet season (average 44.5 ^{o}C) compared to the cold-dry season (average 6 ^{o}C). Goats spent a small percentage of time drinking both during the cold-dry season and the hot-wet season. This is probably due to the time slots of the day that were used in this study to determine the feeding behaviour of the goats. Studies have shown that goats consume less water than sheep (Qinisa & Boomker, 1998; Ferreira *et al.*, 2002; Keskin *et al.*, 2005). During this study it was observed that the goats drank most of their water intake between 1300h–1400h which coincided with the hottest time of the day.

Genotypic variation can also influence preference and selectivity (Warren *et al.*, 1984; Ellis *et al.*, 2005). Experiments have shown differences among populations of livestock, with population representing the genetic diversity arising from subspecies to breeds and breed crosses (Hohenboken, 1986; Odo *et al.*, 2001). In the present study, significant differences were found between the feeding behaviour of the Tswana and the Boer goats. Both breeds devoted the same amount of time (Tswana 66.5 %; Boer 66.2 %) on the range to active foraging. The figures are much higher than that reported by Askin & Turner (1972) for Angora goats (31 %) but are closer to that reported by Mill (1990) for Tunasian goats (77 %) and Aharon *et al.* (2007) on Mamba and Boer goats. In both seasons goats devoted much of the active feeding time to grazing or selection of herbaceous vegetation. The Tswana and Boer goats spent the weighted average of 39.0 % and 46.2 % respectively, of their feeding time grazing. Selection of herbaceous vegetation was also notably higher in the hot-wet season (Tswana 54.4 %; Boer 64.1 %) due to an abundance of lush herbaceous vegetation generally higher in nutritional value. These findings are not consistent with many reports where goats were found to select more browse material than grass (Sidahmed *et al.*, 1981; Lu, 1988; Perevolotsky *et al.*, 1992; Perevolotsky *et al.*, 1998; Berhane & Eik, 2006; Aharon *et al.*, 2007; Yayneshet *et al.*, 2008). The difference between breeds in their time allocations to grazing herbaceous species was notable in the hot-wet season when Boer goats allocated an extra 10 % of their time to grazing compared to Tswana goats, while in the cold-dry season they only allocated an extra 4 % of their time to grazing**.** Both breeds decreased time spent on browsing with advancing period of occupation of a camp. Tswana goats decreased browsing and increased grazing with decline in feed availability compared to Boer goats. This might indicate that Tswana goats have a higher adaptation potential to changes in the vegetation than the Boer goat.

Ruminants display diurnal patterns in time spent grazing and in other activities such as ruminating, being idle and lying down (Sharma *et al*., 1998; Odo *et al.,* 2001; Torrano & Valderrábano, 2005; Schlecht *et al*., 2006). In the present study for both breeds and seasons, a diurnal pattern of foraging was observed. Although goats spent more time grazing than browsing in this study, browsing was significantly high in the morning compared to midday and afternoon while grazing appeared to be high in the afternoon. Dumont *et al*. (1995) in a study on the direct observation of biting for studying grazing behaviour of goats and llamas on garrigue rangelands also observed diurnal variations in diets of both animals where the mornings were spent browsing and afternoons grazing. Torrano & Valderrabano (2005) also observed diurnal pattern of plant utilization where longer time was devoted to browsing earlier in the morning than during the rest of the day. Solanki (1994) on the other hand observed a distinct diurnal pattern for selectivity of forages, with grasses being preferred more in the morning (80 %) followed by bushes (18 %) while in the evening bushes were more preferred (69 %) and grasses (30 %). Diurnal variation feeding behaviour is reported by Steel (1996), stating that when goats are first let out on to pastures in the mornings, they will initially feed unselectively, and later become increasingly selective. In contrast, Benham (1984) cited by Dumont *et al* (1995), states that it is better for ruminants to be selective in the morning than the afternoon. This is supported by results from this study where goats wandered more in the morning (17 %) than the afternoon (12 %), indicating that the level of selection was high in the morning than the afternoon. In the early part of the day, a selective feeding behaviour prevents the rumen from being filled with slowly digestible material that would later limit intake, whereas unselective feeding in the afternoon tops up the rumen ready for the night when little or no feeding is performed (Dumont *et al*, 1995).

It has been reported that diurnal feeding pattern in goats may be modified by factors such as forage availability (Schlecht *et al*., 2006; Sanon *et al*., 2007), environmental stress such as heat and rain (Torrano & Valderrabano, 2005; Sanon *et al*., 2007), frequency of feeding and amount of feeding (Morand-Fehr, 1981; Lu 1988). In the present study, for both breeds and seasons, non-feeding activities were higher during midday compared to morning and afternoon but there were no breed differences. Other studies have also revealed that goats avoid grazing or browsing during the hotter part of the day (Sharma *et al*., 1995).

3.6. Conclusions

The Tswana and Boer goats devoted the same amount of time to active foraging in the False Thornveld of the Eastern Cape. In general grazing was the dominant activity for both breeds and the highest amount of time was spent grazing in the hot-wet season compared to the cold-dry season. When comparisons were made between seasons, Boer goats selected more grass compared to Tswana goats during both seasons. Tswana goats spent more time browsing during the cold-dry season compared to Boer goats, however there was no significant difference between the breeds regarding browsing during the hot-wet season. In general across breeds, a diurnal feeding pattern was observed where browsing was significantly high in the morning compared to midday and afternoon while grazing was high in the afternoon, however, no breed differences were found. Tswana and Boer goats did not differ significantly regarding non-feeding activities. Non-feeding activities were higher for both breeds and seasons during midday compared to the morning and afternoon, but there were no breed differences.

The results suggest that Boer goats spent more time grazing and their diets contained less browse and more grass in both the cold-dry and hot-wet seasons. On the other hand Tswana goats spent more time browsing in the cold-dry season compared to Boer goats and their diets contained less grass and more woody-plant species showing that they exhibit more diversity in their eating choice.

These results have two practical implications for resource partitioning and fire prevention. In areas exploited by cattle, where mixed grazing is practiced, Tswana goats may compete to a lesser extent with cattle than Boer goats and may be more desirable for mixed grazing systems.

Tswana goats may also be more desirable for the control of bush encroachment due to their feeding behaviour which will also deplete combustible mass of herbaceous vegetation and as a result lower fire hazards. Both breeds showed the potential to serve as a management tool in mixed grazing systems.

The variation in preference for grass and browse with different seasons, breeds, the time of the day and period of occupation of a camp, should be taken into account when designing management practices in range areas. Knowledge of feed availability, feeding behaviour and feed preference of free ranging Tswana and Boer goats is fundamental for small scale farmers to develop management strategies aimed at optimum sustained use of the natural vegetation and for the survival of these breeds in the semi arid environment.

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CHAPTER 4

FACTORS AFFECTING WOODY PLANT SPECIES SELECTION OF FREE RANGING TSWANA AND BOER GOATS

4.1. Introduction

Range goats are known to utilize a variety of native browse and herbaceous vegetation (Ramirez *et al*., 1993; Provenza, 1995; Ammar *et al*., 2008; Ramírez-Orduña *et al*., 2008; Kumara Mahipala *et al*, 2009). The contribution made by shrubs and trees to livestock nutrition is considered to be the most important in semi-arid and arid areas (Devendra, 1990; Bhatta *et al*., 2004; Ventura *et al*., 2004; Kamalak, 2006; Tefera *et al*., 2008; Noumi *et al*., 2010; Camacho *et al*., 2010), where extensive livestock production systems are practised (Berhane & Eik, 2006; Gasmi-Boubaker *et al*., 2006). Diet selection is influenced by a complex mix of intrinsic and external factors (Glasser *et al*., 2009). Intrinsic factors include the animal species (le Houeron, 1980; Odo *et al*., 2001) and breed (Celaya *et al*., 2003; Ellis *et al*., 2005); health (Villalba *et al*, 2005); physiological state of the animal (le Houeron, 1980; Barroso *et al*., 1995); and hunger and other physiological feedbacks or control mechanisms (Launchbaugh *et al*., 1999; Jansen *et al*., 2007). External factors include plant availability and accessibility (le Houeron, 1980; Murden & Risenhoover, 1993; Barroso *et al*., 1995; Schlecht *et al*., 2006; Sanon *et al*., 2007); variations in phenology stages and seasons (Illius & Gordon, 1993; Odo *et al*, 2001; Dziba *et al*., 2003; Torrano & Valderrábano, 2005; Schlecht *et al*., 2006; Sanon *et al*., 2007 ; Fraser *et al*., 2009; Glasser *et al*., 2009); plant quality (Ngwa *et al*., 2000; Rafferty & Lamont, 2007; Alonso Diaz *et al*., 2008; Fraser *et al*., 2009; Stolter *et al*., 2009); plant toxicity (Provenza & Malecheck 1984; Glasser *et al*., 2009) and social relations (Provenza & Burrit, 1991: Glasser *et al*., 2009).

It is well known that animals choose different plant species to meet their nutritional requirements, unless limited by forage availability (Sanon *et al*., 2007). Goats exhibit a marked flexibility in diet selection when confronted with seasonal changes in the availability, and nutritional quality (Alonso-Díaz *et al*., 2008), of various constituent plant species on the range

(Yayneshet *et al*., 2008). The selective grazing behaviour of goats buffers the annual variation in the chemical composition of the pastures (Fajemisin *et al*., 1996).
Diet selectivity by herbivores shapes diversity, structure and dynamics of the plant populations (Hodgson & Illius, 1996; Duncan *et al*., 2006). Understanding the reasons why animals prefer some shrubs and not others is important in managing livestock and wildlife with regard to sustaining the shrubland they occupy (Barroso *et al*., 1995). Identification of diet preferences of herbivores can lead to better understanding of the succession development of native rangeland vegetation and help to improve management strategies (Yayneshet *et al*., 2008). The assessment of forage preference could enhance the fodder production in order to improve goat production systems in regions where goat milk and meat contribute to the food needs of the human population (Berhane & Eik, 2006). Yet, the factors that affect diet selection by goats are poorly understood (Torrano & Valderrábano 2005; Fraser *et al*., 2009).

The feeding behaviour of the Tswana and Boer goats in first experiment of the current study, varied between seasons, time of the day and period of occupation of a camp. Tswana and Boer goats, spent less time browsing than grazing and the time spent browsing declined with advancing period of occupation of a camp. It was therefore important to determine if feeding behaviour influenced woody plant species selection of goats and to also determine the roles played by the season, time of the day and period of occupation.

4.2. Materials and methods

4.2.1. Study area, experimental animals and procedures

The study area, experimental animals and procedures have been described in chapter 3. The same procedure for recording the observed browsing activities was used to determine the woody plant species selection pattern of Tswana and Boer goats.

4.3. Statistical analyses

Data was statistically analysed for frequency of utilization using Chi-square test.

4.4. Results

From a wide spectrum of plant species found in the camp used during this trial, the goats encountered and selected a total of thirteen woody plant species. However, five of the thirteen selected woody plant species were utilised in small amounts ranging from 0.1 to 1.2 %. These include *Diospyros lyciodes*, *Dovyalis caffra*, *Lippia javanica*, *Rhus andulata* and forbs. The eight most preferred woody-plant species are listed in Table 4.1. *Scutia myrtina* was the most frequently (29.9 %) consumed woody plant species in the camp followed by *Rhus refracta* (16.3 %), *Grewia occidentalis* (14.0 %), and *Olea africana* (10.8 %). These four woody-plant species accounted for 71 % of the woody plants selected by goats. The remaining four species, A*cacia karroo* (8.7 %), *Coddia rudis* (6.9 %), *Maytenus heterophylla* (6.9 %) and *Ehretia rigida* (6.6 %), accounted for 29 % of the total woody plants selected by goats. Significant differences ($P<0.001$) were found in the percentage time spent selecting the different woody plant species by goats.

Table 4.1. The eight most preferred woody plant species selected by goats listed in order of preference, and indicating their presence in the camp as percentages

Woody-plant Species	**Frequency**	**Percent**	**Percent in the camp**	
			cold-dry season	**hot-wet season**
Scutia myrtina	392	29.9	5	7
Rhus refracta	214	16.3	4	2
Grewia occidentalis	184	14.0	5	7
Olea africana	141	10.8	5	8
Acacia karroo	114	8.7	6	18
Coddia rudis	91	6.9	21	17
Maytenus heterophylla	90	6.9	7	12
Ehretia rigida	86	6.6	3	1

4.4.1. Factors affecting the selection pattern of woody-plant species by goats

4.4.1.1. Season

In general, goats spent more time selecting woody-plant species (P<0.001) in the cold-dry season (56.9 %) than the hot-wet season (43.1 %). Goats also showed a preference for different woody-plant species during the cold-dry season and hot-wet season (Table 4.2). *Scutia myrtina* was the most frequently browsed woody-plant species and time spent browsing this species peaked in the cold-dry season (22.5 %) and decreased in the hot-wet season (7.4 %). On the other hand *R. refracta* was the most preferred woody-plant species selected in the hot-wet season (10.4%) while its selection was low in the cold-dry season (6.0 %).

Table 4.2. Woody plant species selected by goats as influenced by season listed in order of preference for each season

Season			
Cold-dry season		**Hot-wet season**	
Woody-plant Species	Frequency & Percent	Woody-plant Species	Frequency & Percent
Scutia myrtina	295 (22.5)	*Rhus refrater*	136 (10.4)
Grewia occidentalis	97 (7.4)	*Scutia myrtina*	97 (7.4)
Olea Africana	87 (6.6)	*Acacia karroo*	97 (7.4)
Rhus refrater	78 (6.0)	*Grewia occidentalis*	87 (6.6)
Maytenus heterophylla	78 (6.0)	*Olea Africana*	54 (4.1)
Coddia rudis	60 (4.6)	*Ehretia rigida*	52 (4.0)
Ehretia rigida	34 (2.6)	*Coddia rudis*	31 (2.4)
Acacia karroo	17 (1.3)	*Maytenus heterophylla*	12 (0.9)

Grewia occidentalis was the second most preferred woody-plant species in the cold-dry season followed by *O. Africana, R. refracta M. heterophylla, C. rudis, E. rigida* and *A. karroo.* In the hot-wet season the order of preference was different, with *S. myrtina* being the second most preferred species followed by *A. Karroo, G. occidentalis, O. africana, E. rigida, C. rudis* and *M. heterophylla.*

4.4.1.2. Breed

In general, Tswana goats spent more time selecting the woody-plant species than the Boer goats (P<0.001). It was seen that the Tswana goats spent 58.1 % of their selection time collecting woody plants while the Boer goats spent 41.9 % of their selection time using woody palnts.

The differences between Tswana and Boer goats with regard to the frequency of selection of woody-plant species is shown in Table 4.3.

Table 4.3. The effect of breed (Tswana or Boer goat) on the selection of preferred woody plant species by goats

	Tswana		Boer		
Woody-plant Species	**Frequency**	**Percent**	**Frequency**	**Percent**	**Level of Significance**
Scutia myrtina	246	13.1	146	18.8	***
Rhus refracta	112	8.5	102	7.8	NS
Grewia occidentalis	92	7.1	92	7.1	NS
Olea Africana	72	5.5	69	5.3	NS
Acacia karroo	61	4.7	53	4.0	NS
Coddia rudis	63	4.8	28	2.1	***
Martens heterophylla	60	4.6	30	2.3	**
Ehretia rigida	56	4.3	30	2.3	**

NS = not significant * = P < 0.05 ** = P < 0.01 *** P < 0.001

The two breeds showed many similarities as well as minor differences in their preference for woody-plant species. Boer goats showed a higher preference for *S. myrtina* (18.8 %) compared to Tswana goats (13.1 %). Tswana goats, however, preferred *R. refracta* (8.5 %) compared to Boer goats (7.8 %). Preference for *G. occidentalis* was similar for both Tswana (7.0 %) and Boer goats (7.1 %). Similar preferences were also observed in the selection of *O. africana* (Tswana 5.5 %; Boer 5.3 %) and *A. karroo* (Tswana 4.7 %; Boer 4.0 %). Woody-plant species preferred by Tswana goats in comparison to Boer goats included *C. rudis* (Tswana 4.8 %; Boer 2.1 %), *M. heterophylla* (Tswana 4.57 %; Boer 2.3 %) and *E. rigida* (Tswana 4.3 %; Boer 2.3 %)

4.4.1.3. Time of the day

Woody-plant selection varied significantly (P<0.001) during the day. The selection was higher in the morning followed by the afternoon. Selection was lower during midday (28.7 %) when compared to the morning (39 %) and afternoon (32.2 %). In general the goats displayed a definite diurnal variation (P<0.05) in woody-plant species selection as shown in Table 4.4.

Table 4.4. The effect of time of the day on the selection of preferred woody plant species by goats

		Time of the day	
	(0800h-0935h)	**(1100h-1235h)**	**(1400h-1535h)**
Woody-plant Species	Frequency & Percent	Frequency & Percent	Frequency & Percent
Scutia myrtina	129 (9.8)	130 (9.9)	133 (10.1)
Rhus refrater	94 (7.2)	56 (4.3)	64 (4.9)
Grewia occidentalis	71 (5.4)	52 (3.4)	61 (4.7)
Olea Africana	47 (3.6)	37 (2.8)	57 (4.3)
Acacia karroo	51 (3.9)	31 (2.4)	32 (2.4)
Coddia rudis	42 (3.2)	20 (1.5)	29 (2.2)
Maytenus heterophylla	43 (3.3)	23 (1.8)	24 (1.8)
Ehretia rigida	35 (2.7)	28 (2.1)	23 (1.8)

The selection pattern for *S. myrtina*, was the same during the different times of the day (Morning 9.8 %; midday 9.9 %; afternoon 10.1 %). However, *Rhus refracta* and *G. occidentalis* were browsed more in the morning (7.2 % and 5.4 % respectively) followed by afternoon (4.9 % and 4.7 %) and midday (4.3 % and 3.4 % respectively). Selection of *O. africana* was higher in both the afternoon (4.3 %) and morning (3.6 %) compared to midday (2.8 %). A*cacia karroo, C. rudis* and *M. heterophylla* were selected more in the morning (3.9 %, 3.2 % and 3.3 % respectively) followed by the afternoon (2.4 %, 2.2 % and 1.8 % respectively) and midday (2.4 %, 1.5 % and 1.8 % respectively). The selection of *E. rigida* was higher in the morning (2.7 %) compared to at midday (2.1 %) and in the afternoon (1.8 %).

4.4.1.4. Period of occupation

The percentage time spent selecting woody plant species by goats decreased with the advancing period of occupation ($P<0.001$) of a grazing or browsing camp (22.6 % on the first day to 2.3 % on the last day of occupation) as shown in Table 4.5.

Table 4.5. The effect of period of occupation of a camp on the selection of woody plant species by goats

Period of occupation	**Frequency**	**Percentage**
Day 1	297	22.6
Day 2	235	17.9
Day 3	236	18.0
Day 4	196	15.0
Day 5	182	13.9
Day 6	166	12.7

The frequency of woody plant species selection varied during the different observation days as shown in Table 4.6. It appears as though the frequency of browsing decreases the longer the goats stay in the camp.

Table 4.6. The effect of period of occupation of a grazing or browsing camp on the selection of preferred woody plant species by goats

	Period of occupation of a grazing/browsing camp					
	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**
Woody-plant Species	**Freq & %**	**Freq & %**	**Freq & %**	**Freq & %**	**Freq & %**	**Freq & %**
Scutia myrtina	75 (5.7)	84 (6.4)	46 (3.5)	84(6.7)	41 (3.1)	58 (4.4)
Rhus refrater	41 (3.1)	36 (2.7)	43 (3.2)	16 (1.2)	29 (2.2)	49 (3.7)
Grewia occidentalis	41 (3.1)	33 (2.5)	35 (2.7)	36 (2.7)	25 (1.9)	14 (1.1)
Olea africana	38 (2.9)	28 (2.1)	44 (3.4)	4 (0.3)	14 (1.1)	13 (1.0)
Acacia karroo	40 (3.1)	18 (1.4)	17 (1.3)	11 (0.8)	22 (1.7)	6 (0.5)
Coddia rudis	14 (1.1)	15 (1.1)	16 (1.3)	21 (1.6)	18 (1.4)	7 (0.5)
Maytenus heterophylla	29 (2.2)	11 (0.8)	24 (1.8)	8 (0.6)	11 (0.8)	7 (0.5)
Ehretia rigida	19 (1.5	10 (0.8)	11 (0.8)	12 (0.9)	12 (0.7)	12 (0.9)
Total Frequency	**297**	**235**	**236**	**196**	**182**	**166**
Total Percent	**22.6**	**17.9**	**18.0**	**14.9**	**13.9**	**12.7**

Definite diurnal patterns in woody plant selection were observed in both the Tswana and Boer goats during the cold-dry season and the hot-wet season (Table 4.7). Tswana goats had a higher frequency of woody plant selection in the cold-dry season than in the hot-wet season. The Boer goats, on the other hand, maintained the same frequency of woody plant selection in both the cold-dry season and the hot-wet season. During both seasons, Tswana goats had a higher frequency of woody plant selection compared to Boer goats.

Table 4.7. The effect of season and time of the day on the preference for woody plants (n=1312) by Tswana and Boer goats

Factor	Breed				
	Tswana		Boer		
	Frequency	Percent	Frequency	Percent	Significance level
Season					
Cold-dry	474	36.1	272	20.7	***
Hot-wet	288	22.0	278	21.2	NS
Time					
(0800h-0935h)	320	24.4	192	14.6	***
(1100h-1235h)	193	14.7	184	14.0	NS
(1400h-1535h)	249	18.9	174	13.3	***

NS = not significant   * = $P < 0.05$ ** = $P < 0.01$ *** $P < 0.001$

Tswana goats selected more woody-plant species in the morning followed by the afternoon and midday. Boer goats on the other hand did not vary their frequency of woody plant selection much throughout the day.

4.4.1.5. Woody plant species selected by Tswana and Boer goats during the cold-dry season and the hot-wet season at different times of the day

Woody plant selection by Tswana and Boer goats varied during the different seasons and times of the day as shown in Table 4.8.

4.4.1.5. (a) *Scutia myrtina*

Tswana goats spent the same amount of time in the morning, midday and afternoon (18.2 %) selecting *S. myrtina* during the cold-dry season. Boer goats also spent the same amount of time selecting *S. myrtina* both in the morning and midday (16.7 %), but increased their selection in the afternoon (20 %). During the hot-wet season, the selection of *S. myrtina* by both breeds increased compared to the cold-dry season. Tswana goats had a higher preference for *S. myrtina* in the afternoon (26.3 %) and a similar preference in the morning and midday (21.1 %). Boer goats however showed a higher preference for *S. myrtina* during midday (37.5 %) followed by morning (31.3 %) and afternoon (25.0 %).

Table 4.8. The effect of the season and time of the day on the browsing percentage of specific woody plants by Tswana and Boer goats

Woody-plant species	Season	Breed	Time		
			(08:00-09:35)	(11:00-12:35)	(14:00-15:35)
Scutia myrtina	Cold-dry season	Tswana	18.2	18.2	18.2
		Boer	16.7	16.7	20.0
	Hot-wet season	Tswana	21.1	21.1	26.3
		Boer	31.3	37.5	25.0
Rhus refracta	Cold-dry season	Tswana	18.5	11.1	11.1
		Boer	12.5	8.3	16.7
	Hot-wet season	Tswana	18.5	22.2	18.5
		Boer	20.8	25.0	16.7
Grewia occidentalis	Cold-dry season	Tswana	14.3	17.9	21.4
		Boer	15.4	11.5	11.5
	Hot-wet season	Tswana	21.4	17.9	7.1
		Boer	23.1	23.1	15.4
Olea Africana	Cold-dry season	Tswana	26.3	5.3	21.1
		Boer	9.1	9.1	22.7
	Hot-wet season	Tswana	10.5	15.8	21.1
		Boer	18.2	22.7	18.2
Acacia karroo	Cold-dry season	Tswana	15.8	5.3	10.5
		Boer	6.3	0.0	0.0
	Hot-wet season	Tswana	21.1	21.1	26.3
		Boer	31.3	37.5	25.0
Coddia rudis	Cold-dry season	Tswana	31.6	15.8	15.8
		Boer	12.5	12.5	18.8
	Hot-wet season	Tswana	21.1	5.3	10.5
		Boer	18.8	25.0	12.5
Maytenus heterophylla	Cold-dry season	Tswana	29.4	17.7	29.4
		Boer	23.1	7.69	23.1
	Hot-wet season	Tswana	17.7	0.0	5.9
		Boer	23.1	7.7	15.4
Ehretia rigida	Cold-dry season	Tswana	14.3	9.5	14.3
		Boer	21.1	10.5	5.3
	Hot-wet season	Tswana	28.6	19.1	14.3
		Boer	31.6	21.1	10.5

4.4.1.5. (b) *Rhus refracta*

During the cold-dry season, Tswana goats selected more *R. refracta* in the morning (18.5 %) compared to midday and the afternoon (11.1 %) when a similar percentage was selected. Boer goats however showed a higher preference for *R. refracta* in the afternoon (16.7 %) compared to morning (12.5 %) and midday (8.3 %). During the hot-wet season the selection pattern of Tswana goats changed with a higher preference occurring at midday (22.2 %) than in either the morning (18.5 %) or the afternoon (18.5 %). Boer goats also showed the same pattern of preference for *R. refracta* with a higher selection at midday (25.0 %) compared to the morning (20.8 %) and afternoon (16.7 %).

4.4.1.5. (c) *Grewia occidentalis*

Grewia occidentalis was better utilized in the afternoon (21.4 %) by Tswana goats, followed by midday (17.9 %) and morning (14.29%) browsing during the cold-dry season. Boer goats however preferred utilizing *G. occidentalis* in the morning (15.38%) compared to both midday and afternoon (11.5 %). In the hot-wet season, Tswana goats had a higher preference for *G. occidentalis* in the morning (21.5 %) followed by the afternoon (17.9 %). The lowest selection of *G. occidentalis* by Tswana goats was in the afternoon (7.1 %). Boer goats selected the same percentage (23.1) of *G. occidentalis* both in the morning and midday compared to the afternoon (15.4%).

4.4.1.5. (d) *Olea africana*

In the cold-dry season, the selection of *O. africana* by Tswana goats was higher in the morning (26.3 %) and afternoon (21.1 %) and low at midday (5.3 %). Boer goats however showed high preference for *O. africana* in the afternoon (22.7 %) and low preference both in morning and midday (9.1 %). During the hot-wet season, preference for *O. africana* by Tswana goats was high in the afternoon (21.1 %) followed by midday (15.8 %) and low in the morning (10.5 %). Boer goats on the other hand preferred *O. africana* more during midday (22.7 %) compared to both morning and afternoon (18.2 %).

4.4.1.5. (e) *Acacia karroo*

A high selection of *A. karroo* by Tswana goats occurred in the morning (15.8 %) followed by the afternoon (10.5 %) and midday (5.3 %). Boer goats also selected *A. karroo* in the morning (6.3 %) while none was selected during midday and the afternoon. During the hot-wet season, Tswana goats selected more *A. karroo* in the afternoon (26.3 %) while selection in the morning and midday was the same (21.1 %). Boer goats however selected more *A. karroo* during midday (37.5 %) followed by the morning (31.3 %) and afternoon (25.0 %).

4.4.1.5. (f) *Coddia rudis*

During the cold-dry season, Tswana goats preferred *C. rudis* in the morning (31.6 %) when compared to midday (15. 8%) and afternoon (15.9 %). Boer goats, however, selected *C. rudis* more in the afternoon (18.8 %), and a similar preference was shown in the morning and midday 12.5 %). In the hot-wet season, Tswana goats preferred browsing *C. rudis* in the morning (21.1 %) followed by the afternoon (10.5 %) and midday (5.3 %). Boer goats however preferred browsing *C. rudis* more at midday (25 %) followed by morning (18.8 %) and afternoon (12.5 %).

4.4.1.5. (g) *Maytenus heterophylla*

Tswana goats selected similar percentages of *M. heterophylla* both in the morning and afternoon (29.4 %) compared to midday (17.7 %). The same trend was also observed with Boer goats where their preference for *M. heterophylla* was similar in the morning and afternoon (23.1 %) and low during midday (1.7 %). During the hot-wet season, Tswana goats selected more *M. heterophylla* in the morning (23.1 %) than in the afternoon (15.4 %), but none during midday. Boer goats also selected more *M. heterophylla* in the morning (23.1 %) followed by afternoon (15.4 %) and less at midday (7.7 %).

4.4.1.5. (h) *Ehretia rigida*

During the cold-dry season, Tswana goats showed similar preference for *E. rigida* both in the morning and afternoon (14.3 %) when compared to midday (9.5 %). Boer goats, however, showed a high preference for the same plant in the morning but this declined by midday (10.5 %) and afternoon (5.3 %). In the hot-wet season both Tswana and Boer goats selected more *E. rigida* in the morning (28.6 % and 31.6 respectively) than at midday (19.1% and 21.1 % respectively) and in the afternoon (14.3 % and 10.5 % respectively)

4.5. Discussion

Goats exhibit marked flexibility in diet selection when confronted with seasonal changes in availability and nutritional changes of various constituent plant species (Morand-Fehr, 1981; Yayneshet *et al*. 2008). Negi *et al*. (1993) point out that goats should be regarded as highly selective in its foraging behaviour. Jones (1953) states that in some plant species, the differences in preference are not only due to their chemical makeup but to their morphological features as well. Degree of selection by goats depends on plant species offered and stage of growth of forage (Morand-Fehr *et al*., 1980). The Tswana and Boer goats foraged upon diverse woody-plant species. Both breeds selected similar types of woody plant species. The eight most preferred woody-plant species were similar for both breeds, however, the frequency of selection and order of preference were different. Across treatments, Tswana goats exhibited a higher frequency of woody plant selection compared to Boer goats. The difference between breeds in their time allocations to woody plant species selection was notable in the cold-dry season when Tswana goats allocated an extra 15 % of their time to woody-plant selection compared to Boer goats. In the hot-wet season Tswana goats decreased their frequency of woody plant section. Boer goats maintained the same frequency of woody plant selection in both the cold-dry season and the hot-wet season. Boer goats showed a higher preference for *S. myrtina* while Tswana goats showed a higher preference for *R. refracta.* Both breeds showed similar preferences for *G. occidentalis*, *O. africana* and *A. karroo*. Tswana goats however showed a greater preference for *C. rudis*, *M. heterophylla* and *E. rigida* than the Boer goats did.

In a study by Bjelland and Grøva (1997) on woody-plant preference by indigenous Ciskeian goats and improved Boer goats, both breeds selected in a similar fashion six preferred woody-plant species (*Acacia karroo*, *Rhus lucida*, *Grewia occidentalis*, *Scutia myrtina*, *Ehretia rigida* and *Maytenus heterophylla*) though the order of preference was different.

Differences in the frequency of woody plants selected by goats were observed during the different seasons. This is in agreement with results from studies by Torrano & Valderrabano (2005) and Yayneshet *et al*. (2008) where goats exhibited a seasonal and diurnal pattern of plant utilization. In general, the frequency of woody-plant species selection was higher in the cold-dry season than the hot-wet season. *Scutia myrtina* was the most preferred woody-plant species during the cold-dry season followed by *G. occidentalis, O. africana, R. refracta, M. heterophylla, C. rudis, E. rigida,* and *A. karroo.* During the hot-wet season *R. refracta* was the most preferred followed by *S. myrtina*, *A. karroo, G. occidentalis, O. africana, E. rigida, C. rudis* and *M. heterophylla.*

Woody-plant species selection pattern changed during the course of the day. A higher percentage of woody-plants were selected during the morning. Selection was lower during midday but increased again slightly during the afternoon. Regardless of the breed of goat or the season, only *G occidentalis* and *O. Africana* were the most preferred woody-plant species in the afternoon, while all the other woody-plant species were selected with the highest frequency in the morning. During the cold-dry season, the following woody-plant species were preferred by Tswana goats in the morning*: S. myrtina, R. refracta, O. africana, A. karroo, C. rudis, M. heterophylla and E. rigida.* Boer goats on the other hand preferred *G. occidentalis, A. Karroo, M. heterophylla* and *E. rigida.*

During midday, both breeds showed no particular preference for specific species. In the afternoon however, Tswana goats showed higher preference for *G. occidentalis* and *M. heterophylla* while Boer goats preferred *S. myrtina, R. refracta, O. africana, C. rudis* and *M. heterophylla.* During the hot-wet season, woody-plant species most preferred by Tswana goats in the morning were *G. occidentalis, C. rudis, M. heterophylla and E. rigida.* Boer goats showed a higher preference for *G. occidentalis, M. heterophylla* and *E. rigida.* During midday, Tswana goats showed a higher preference for only *R. refracta* while Boer goats showed a higher preference for *G. occidentalis, M. heterophylla* and *E. rigida.* In the afternoon Tswana goats preferred browsing *S. myrtina, O. africana* and *A. karroo* while Boer goats did not show a higher preference for any particular woody-plant species.

During both seasons and for both breeds of goat, the frequency of woody-plant selection decreased with advancing period of occupation. Browse was the preferred feed when feed availability was high, supporting the findings of Bjelland & Grova (1997) and Mogorosi *et al.* (1996). When feed availability declined, goats decreased their frequency of woody-plant selection as they were forced to eat more grass (Gøthasen, 1997; Dziba & Raats, 1998). Negi *et al*., 1993) observed that when food resources are diversified, a goat's feeding behaviour is highly selective and when plant diversity narrows down, it resorts to generalist behaviour.

Both deciduous and evergreen plant species were among the more preferred species. Deciduous woody plant species are usually preferred above evergreen species (Papachristou & Nastis, 1996) as they are easily available and highly nutritious. They are also more preferred in the hot-wet season than evergreen species (Gennin & Pijoan, 1993). The botanical survey showed that during the cold-dry season goats foraged in a range that had a total of 59 % of the eight most preferred woody plant species (Table 4.1). In the hot-wet season the percentage of the woody plant species was higher, constituting about 72 % of the total plants in the range. Woody plant species that each constituted less than 10 % of the plants in the camp during both seasons were amongst the top four most preferred plants. Ngwa *et al*. (2000), states that plant species that constitute a small proportion of the entire range make a large part of the diet of animals. Barroso *et al*. (1995) also found a trend of higher selectivity for species with a lower availability. It could be argued that certain plant types are relatively rare because they are the plant types the goats select. On the other hand, there may be an inherent tendency by the generalist forager towards selective grazing of relatively rare plant types which are rare for reasons other than herbivory.

Grewia occidentalis, *A. karroo and E. rigida* are deciduous, so have less available browse in the cold-dry season than the hot-wet season, while *S. myrtina* is evergreen thus their browse availability does not change with season. *G. occidentalis* is regarded as very palatable and highly preferred (Gøthasen, 1997; Haschick & Kerly, 1997) and has been ranked as the second most preferred woody-plant species after *S. myrtina* (Dziba, 2000; Dziba *et al*., 2003). This supports the finding of the current study where *G. occidentalis,* was the second most preferred woody-plant species after *S.* myrtina, during the cold-dry season; but the fourth most preferred in the hot-wet season. *Scutia myrtina* is regarded as palatable during the dry season (Raats *et al*., 1996b) when deciduous species have shed their leaves. A*cacia. karroo and E. rigida* are also palatable but preference for these species declines as the period of occupation increases (Mogorosi *et al.*, 1996). Studies have shown that goats show a particular preference for *A. karroo* (Mapuma *et al*., 1996; Mogorosi *et al*., 1996; Raats *et al*., 1996b). Although results from the current study show *A. karroo* to be the 8th in order of preference during the cold-dry season, it was still high in preference during the hot-wet season following *R. refracta* and *S. myrtina*. This is mainly a function of the high occurrence of *A. karroo* (Table 4.1) in the study area and the subsequent high encounter rate of goats with *A. karroo* in the range (Raats *et al*., 1996b; Gøthasen, 1997). The proportion of deciduous trees in the range might determine productivity of goats in semi-arid savannas since they lose their leaves in the dry season (Dziba *et al*., 2003).

4.6. Conclusions

Goats foraged upon a wide spectrum of woody-plant species found in the camp. This demonstrates the importance of woody-plant species in semi-arid and arid areas, contributing to the increase in availability of forage resources to free ranging animals. It is however important to highlight that the type of vegetation, availability of woody plant species and phenological stage of the plant influence the woody plant selection by goats. Variations in woody-plant species proportions as well as changes in their quality may modify intake levels and therefore the variation in preference for some plant species with grazing season and time of day should be taken into account when designing management practices in forestry areas. An understanding of plant species selection by free ranging Tswana and Boer goats is important for management strategy and profitable animal production. This information could allow for optimal forage allocation to different types of ruminants, selecting species for re-seeding deteriorated ranges, predicting the outcome of overgrazing by different animals and to identify new species on which to base the management. In the present study, plants that contributed a small proportion of the entire range made a large part of the diet of Tswana and Boer goats. This suggests that careful monitoring of the vegetative community will be required in the light of the different foraging pressures on scarce plant types. Goats may be an important inclusion in multi-herbivore ranging systems in communal ranges of semi-arid areas.

In this experiment, differences in the frequency of woody plants selected by goats were observed during the different seasons and times of the day. During both seasons and for both breeds of goat, the frequency of woody-plant selection decreased with advancing period of occupation. It was therefore of importance to determine if the plant selection pattern is influenced by the nutrient content of the selected forage.

CHAPTER 5

NUTRITIVE VALUE OF FORAGES SELECTED BY FREE RANGING TSWANA AND BOER GOATS

5.1. Introduction

The majority of goats in the world exist on rangelands (Mellado *et al*., 2004; Schlecht *et al*., 2006) where seasonal shortages and low quality of available feed resources are considered the most widespread technical constraints to small-stock production systems in many parts of the developing world (Osuji & Odenyo, 1997; Ouedraogo-Kone *et al*., 2006; Kawas *et al*., 2010). In South Africa, approximately 80% (68.4 million ha) of land available for agricultural purposes can only be utilised effectively by free ranging herbivores (de Waal, 1990). Although the natural vegetation provides the bulk of the nutrients for domestic livestock and all the nutrients for wild herbivores (Harris *et al*., 1967), its ability to sustain animal production varies substantially according to climate (Sanon *et al*., 2007), geography, plant community, bush encroachment and range deterioration (Keskin *et al*., 2005). In arid and semi arid areas, the environment is characterised by chronic deficiencies in certain nutrients and periodic intervals of harsh climate and food shortages (Ramirez *et al*, 2004). Nevertheless these areas offer an important potential for goat production (Ramirez *et al*., 1990) which in most cases represent the sole source of income to farmers (Morand-Fehr *et al*., 2004). The survival of grazing animals is thus, among other factors dependent on the ability to digest low quality roughages, store fat, withstand heat and cold, and recycle deficient nutrients (Raats, 1993). The grazing ruminant therefore exists in a highly dynamic situation where its productivity is primarily dependent on the net nutrient intake, which exceeds maintenance requirements (Laredo *et al*., 1991), and which in turn relies directly on the quantity and quality of food intake. In range animals, this process commences with the ability of the animal to select large quantities of nutritious forage components (Raats, 1993; Sun *et al*., 2008).

The need to evaluate the nutritional characteristics of diets consumed by range ruminants is well recognised (Cerrillo *et al*., 2006). Knowledge of the nutritive value of the diet as selected by grazing or browsing animals is of primary importance in estimating the productivity of the range

(Harris *et al*., 1967; France *et al*., 2000; Sun *et al*., 2008). Any assessment of the nutritional value of the range using goats may lead to the identification of the nutritional constraints that affect efficient rangeland production of livestock (Allison, 1985; Ramirez, 1999; Cerrillo *et al*., 2006). Sub-optimal animal production on rangeland is the result of several factors of which nutrient intake is probably the most common (Allison, 1985). However, not much is known about the nutritive value of the diet selected by free ranging goats (Fraser *et al*., 2009), especially the Tswana goat. Tswana and Boer goats from the experiment on species selection in the current research varied their plant species selection during the different seasons, time of the day and period of occupation of a camp. It was therefore of importance to determine if nutrient content of the diet was also influenced by seasons, time of the day and period of occupation of a camp. The objective of the current study was to compare the nutritive values of diets selected by free ranging Tswana and Boer goats during the cold-dry season and the hot-wet season in the False Thornveld of the Eastern Cape.

5.2. Materials and Methods

5.2.1. Study area and experimental animals

The study area and experimental animals are described in Chapter 3.

5.2.2. Experimental procedures

At 0700h on Tuesdays and Thursdays during the study period, the six goats (3 Tswana and 3 Boer) which had oesophageal fistulae were equipped with remote controlled fistula valves and allowed into the plots to graze/browse. These valves allow the collection of samples without the observer distracting the goat during the selection of plant material. Fistula valve samples were collected from the same six fistulated goats during the rest of the day (until 1535h) at the following hours (8, 9, 11, 12, 14, 15) while the animals were actively grazing/browsing. During collection, the valve remained open until sufficient extrusa had been collected (15 minutes) and then closed when the oesophagus was clear of plant material. Samples were allowed to drop to the ground where they were collected. Any debris adhering to these samples was removed and the clean sample kept in labelled plastic bags on ice in a cooler box. All extrusa samples were returned to the laboratory and stored in a deep freeze prior to drying and milling. Each sample was freeze-dried and hand separated into bush (woody species) and grass components (including forbs), which were then weighed separately. The bush and grass components were recombined and the sample milled through a 1mm sieve. These oesophageal valve samples were analysed for nitrogen by the Kjeldhal method (AOAC, 1990) and crude protein was calculated as 6.25 x N. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were analysed using the filter bag technique (ANKOM Technology). All results were then calculated and expressed on a dry matter basis.

5.3. Statistical analyses

Data were analysed using Generalised Linear Model Procedures (GLM) of SAS (2003) with breed, season, time of the day and period of occupation and their interactions as the main factors in the model.

5.4. Results

The season, breed, time of the day and period of occupation of a grazing/browsing camp significantly influenced the nutrient content of forages selected by free ranging goats as shown in Table 5.1.

Table 5.1. The effect of season, breed of goat, time of day and the period of occupation of camp on the nutritive value of diets selected by free ranging goats (mean ± SE)

FACTOR	CP	NDF	ADF	ADL
Season				
Cold-dry season	5.4 ± 0.15[a]	48.2 ± 1.02[a]	34.3 ± 0.72[b]	18.0 ± 0.52[a]
Hot-wet season	9.5 ± 0.15[b]	53.8 ± 1.02[b]	37.5 ± 0.72[a]	19.5 ± 0.52[a]
Breed				
Tswana	7.7 ± 0.15[a]	52.4 ± 1.02[a]	37.0 ± 1.25[a]	20.0 ± 0.52[a]
Boer	7.2 ± 0.15[a]	49.5 ± 1.02[a]	34.8 ± 1.25[b]	17.5 ± 0.52[b]
Time				
(0800h-0935h)	7.7 ± 0.18[a]	52.0 ± 1.25[a]	36.8 ± 0.89[a]	20.4 ± 0.64[a]
(1100h-1235h)	7.1 ± 0.18[a]	48.3 ± 1.25[b]	33.8 ± 0.89[b]	17.6 ± 0.64[b]
(1400h-1535h)	7.5 ± 0.18[a]	52.4 ± 1.25[a]	37.1 ± 0.89[a]	18.3 ± 0.64[b]
Day				
1	8.1 ± 0.26[a]	52.4 ± 1.77[a]	40.9 ± 1.25[a]	23.0 ± 0.90[a]
2	6.8 ± 0.26[b]	54.0 ± 1.77[a]	37.1 ± 1.25[b]	20.3 ± 0.90[b]
3	7.7 ± 0.26[a]	53.6 ± 1.77[a]	363 ± 1.25[b]	18.7 ± 0.90[bc]
4	7.6 ± 0.26[a]	52.1 ± 1.77[a]	34.6 ± 1.25[bc]	17.1 ± 0.90[c]
5	7.7 ± 0.26[a]	46.8 ± 1.77[b]	32.0 ± 1.25[c]	17.2 ± 0.90[c]
6	6.7± 0.26[b]	47.1 ± 1.77[b]	34.6 ± 1.25[c]	16.2 ± 0.90[c]

Means in the same column with different superscripts are significantly different (P<0.05)

5.4.1. Effect of season, breed, time of the day and period of occupation on the crude protein (CP) content of forages selected by goats

There were notable differences (P<0.001) in the seasonal concentrations of crude protein in diets selected by free ranging goats (Table 5.1). On average the crude protein content of the selected diets pooled over treatments varied significantly (P<0.0001) between seasons (cold-dry: 5.4 % SE = 0.15 and hot-wet 9.5 % SE = 0.15). No breed difference (P>0.05) was found between Tswana and Boer goats in the crude protein content of selected forages. Similarly, there were no diurnal variations in crude protein content of forages selected by goats. There were however significant differences (P=0.001) in the CP content of forages selected on different observation days. The crude protein content of forages selected by Tswana and Boer goats did not differ significantly within each season as shown in Table 5.2.

Table 5.2. The effect of season on the nutritive value of diets selected by Tswana and Boer goats (Percent least square means)

SEASON	BREED	CP	NDF	ADF	ADL
Cold-dry season	Tswana	5.8[a]	50.0[a]	35.9[a]	20.2[a]
	Boer	5.0[a]	46.2[a]	32.7[b]	15.9[b]
Hot-wet season	Tswana	9.5[a]	54.8[a]	38.2[a]	19.9[a]
	Boer	9.4[a]	52.7[a]	36.8[a]	19.1[a]
	SE	0.21	1.45	1.02	0.74

Means in the same column with different superscripts are significantly different (P<0.05)
Crude protein (CP), Neutral Detergent fibre (NDF), Acid Detergent Fibre (ADF), Acid Detergent Lignin (ADL)

However, when comparisons were based on breed, by day and season interaction, there were significant differences (P<0.0001) in CP content of selected forages both during cold-dry season and hot-wet season as shown in Tables 5.3 and Table 5.4 respectively.

Table 5.3. Effect of breed and period of occupation on the nutritive value of forages selected by free ranging Tswana and Boer goats during the cold-dry season

BREED	DAY	CP (%)	NDF (%)	ADF (%)	ADL (%)
Tswana	1	6.9[a]	56.7[a]	40.2[a]	21.8
Tswana	2	5.8[abc]	47.4[ab]	34.1[ab]	22.7
Tswana	3	5.9[abc]	47.2[ab]	34.3[ab]	19.7
Tswana	4	6.0[abc]	48.7[ab]	33.0[ab]	19.8
Tswana	5	5.7[abcd]	56.1[ab]	39.4[a]	19.2
Tswana	6	4.1[cd]	43.6[bc]	34.4[ab]	17.7
Boer	1	6.1[abc]	52.6[ab]	35.8[ab]	20.3
Boer	2	5.7[abc]	58.7[a]	40.4[a]	16.6
Boer	3	6.5[a]	55.6[ab]	38.3[ab]	19.3
Boer	4	4.2[cd]	49.2[ab]	29.8[b]	12.4
Boer	5	3.1[d]	27.8[d]	17.7[c]	8.3
Boer	6	4.7[bc]	33.4[cd]	34.4[ab]	18.2
SE		0.50	4.47	3.21	2.18

Means in the same column with different superscripts are significantly different ($P < 0.05$).
Crude protein (CP), Neutral Detergent fibre (NDF), Acid Detergent Fibre (ADF), Acid Detergent Lignin (ADL)

Significant differences ($P<0.0001$) were found in the crude protein content of selected forages during the cold-dry season.

Table 5.4. Effect of breed and period of occupation on the nutritive value of forages selected by free ranging Tswana and Boer goats during hot-wet season.

BREED	DAY	CP (%)	NDF (%)	ADF (%)	ADL (%)
Tswana	1	10.3^{bc}	50.2	43.9	24.3^{ab}
Tswana	2	8.1^{d}	55.6	36.2	21.1^{b}
Tswana	3	8.9^{bcd}	56.7	36.9	16.6^{cd}
Tswana	4	10.0^{bc}	55.8	39.4	21.2^{b}
Tswana	5	10.1^{bc}	52.6	36.6	21.4^{b}
Tswana	6	9.7^{bc}	57.9	35.6	14.9^{d}
Boer	1	9.1^{bcd}	48.7	43.8	25.4^{a}
Boer	2	7.7^{d}	54.2	37.1	20.8^{b}
Boer	3	9.3^{bc}	54.9	35.4	19.1^{bc}
Boer	4	10.2^{bc}	54.7	36.4	15.1^{d}
Boer	5	11.9^{a}	50.5	34.2	19.9^{bc}
Boer	6	8.3^{bcd}	53.4	34.1	14.1^{d}
SE		0.52	1.29	1.09	1.25

Means in the same column with different superscripts are significantly different ($P < 0.05$).
Crude protein (CP), Neutral Detergent fibre (NDF), Acid Detergent Fibre (ADF), Acid Detergent Lignin (ADL)

Graphical illustrations of the effect of season and period of occupation on the crude protein content of forages selected by goats during cold-dry season and hot-wet season are presented in Figure 5.1 and Figure 5.2 respectively.

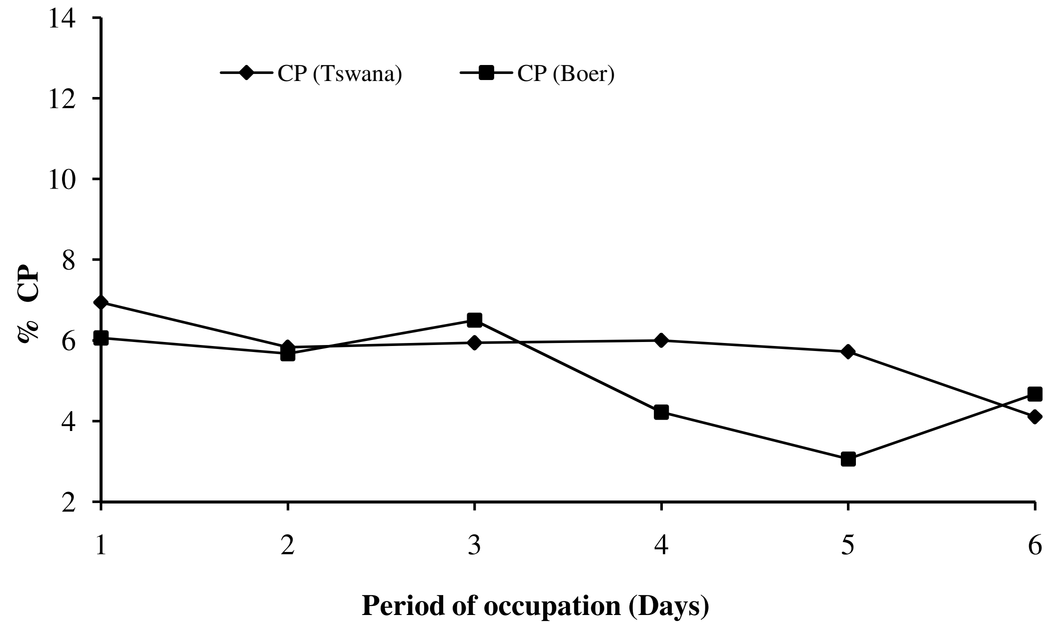

Figure 5.1. Crude protein content of diets selected by free ranging Tswana and Boer goats during the cold-dry season.

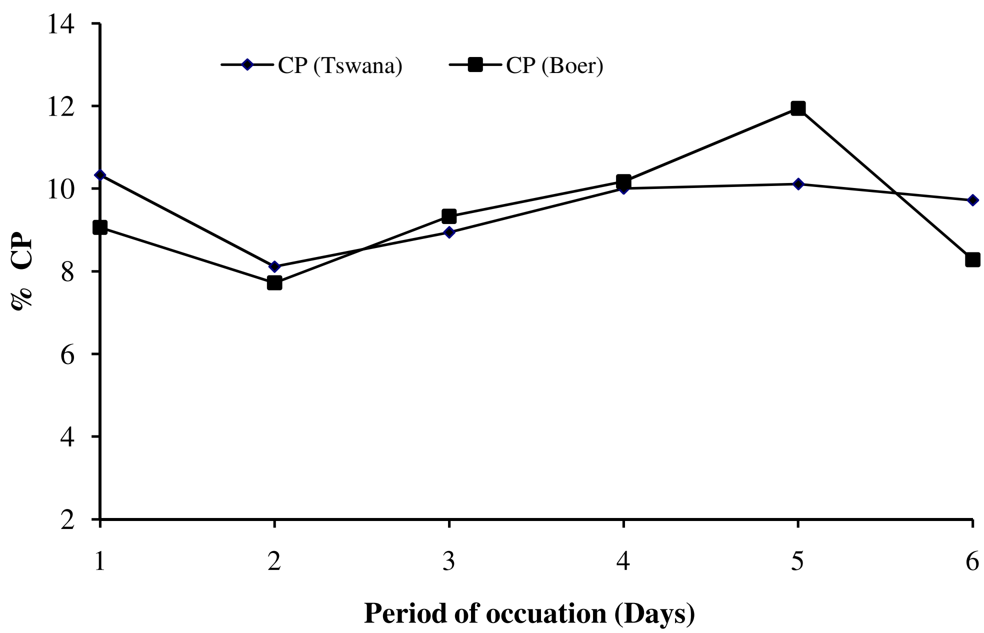

Figure 5.2. Crude protein content of diets selected by free ranging Tswana and Boer goats during the hot-wet season.

5.4.2. Effect of season, breed, time of the day and period of occupation on the neutral detergent fibre (NDF) content of forages selected by goats

There were notable differences (P<0.001) in the seasonal concentrations of NDF in diets selected by free ranging goats (Table 5.1). On average the NDF content of the selected diets varied significantly (P=0.001) between seasons (cold-dry season 48.1 % SE = 1.02; and hot wet season 53.8 % SE = 1.02). There was no difference (P>0.05) found between Tswana and Boer goats in the NDF content of selected forages (52.4 % and 49.5 % SE = 1.02). Regardless of breed and season, there were diurnal variations (P=0.04) in the NDF content of forages selected by goats. There were also significant differences (P=0.01) in the NDF content of forages selected by goats on different observation days. The NDF content of forages selected by Tswana and Boer goats during the period of occupation of a grazing/browsing camp differed significantly (P<0.05) during cold-dry season as shown in Table 5.3 and graphically illustrated in Figure 5.3. However, during the hot-wet season there was no significant difference (P>0.05) in NDF content of selected forages with advancing period of occupation of a grazing/browsing camp as shown in Table 5.4 and graphically illustrated in Figure 5.4.

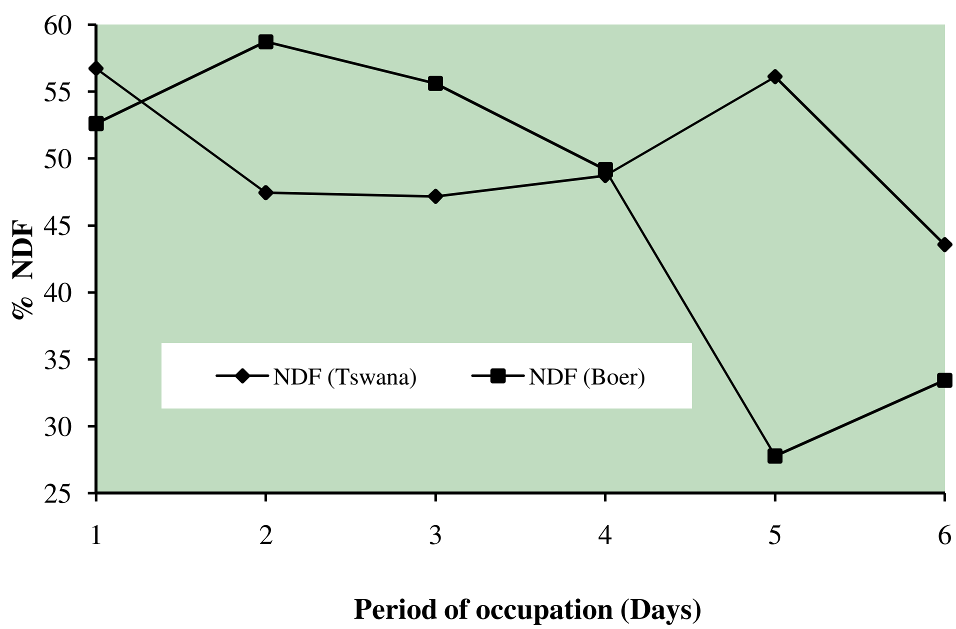

Figure 5.3. The NDF content of diets selected by free ranging Tswana and Boer goats during the cold-dry season

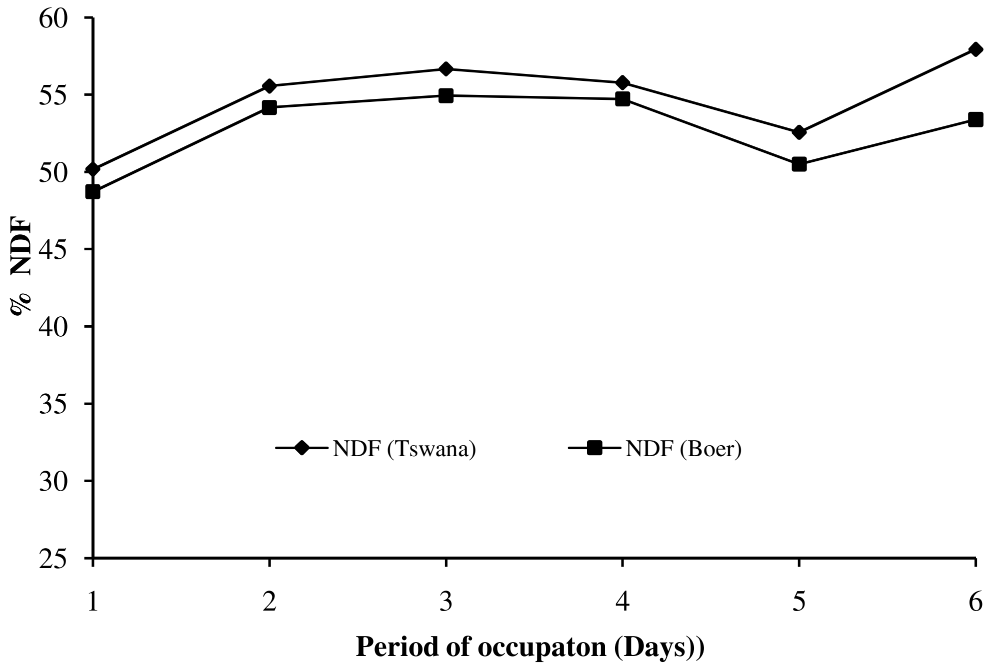

Figure 5.4. NDF content of diets selected by free ranging Tswana and Boer goats during the hot-wet season

5.4.3. Effect of season, breed, time of the day and period of occupation on the acid detergent fibre (ADF) content of forages selected by goats

There were notable differences (P=0.002) in the seasonal concentrations of ADF in diets selected by free ranging goats (Table 5.1). The average ADF content of diets selected by goats, varied significantly (P=0.002) between the cold-dry season (34.3 % SE = 0.72) and the hot-wet season (37.5 % SE = 0.72). There was a breed difference (P=0.03) found between Tswana and Boer goats in the ADF content of selected forages (37.0 % and 34.8 % SE = 1.25 respectively). Regardless of breed and season, there were diurnal variations (P=0.02) in the ADF content of forages selected by goats. Goats selected forages with higher ADF content both in the mornings and afternoons and those with lower ADF during midday. There were also significant differences (P<0.001) in the ADF content of forages selected by goats on different observation days. The ADF content of forages selected by Tswana and Boer goats during the period of occupation of a grazing/browsing camp differed significantly (P=0.003) during the cold-dry season as shown in Table 5.3 and graphically illustrated in Figure 5.5. However, during the hot-wet season there was no significant difference (P>0.05) in ADF content of selected forages with advancing period of occupation of a grazing/browsing camp as shown in Table 5.4 and illustrated in Figure 5.6. This followed the same trend as found for the NDF content of the selected diets.

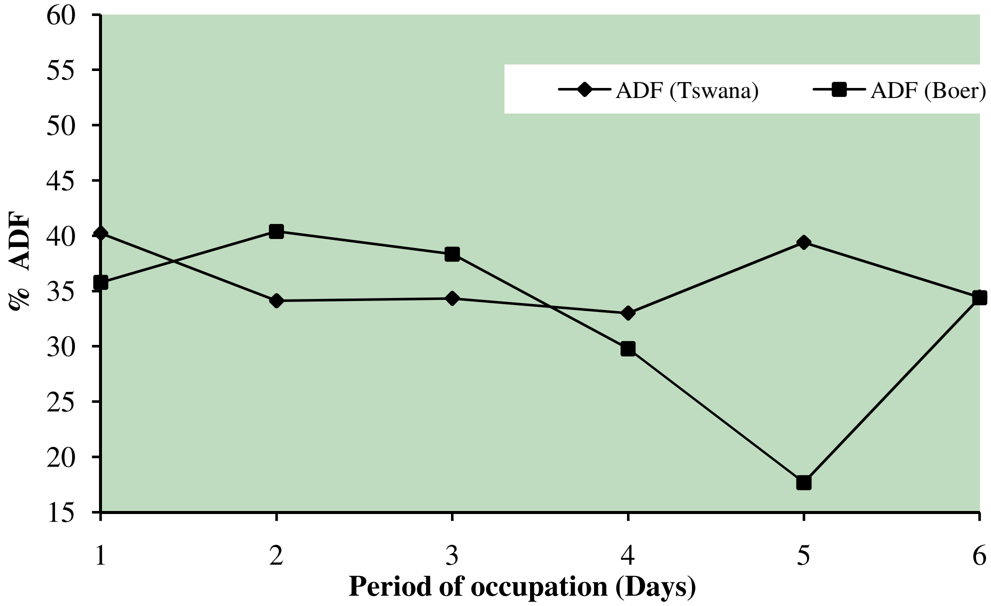

Figure 5.5. ADF content of diets selected by free ranging Tswana and Boer goats during the cold-dry season

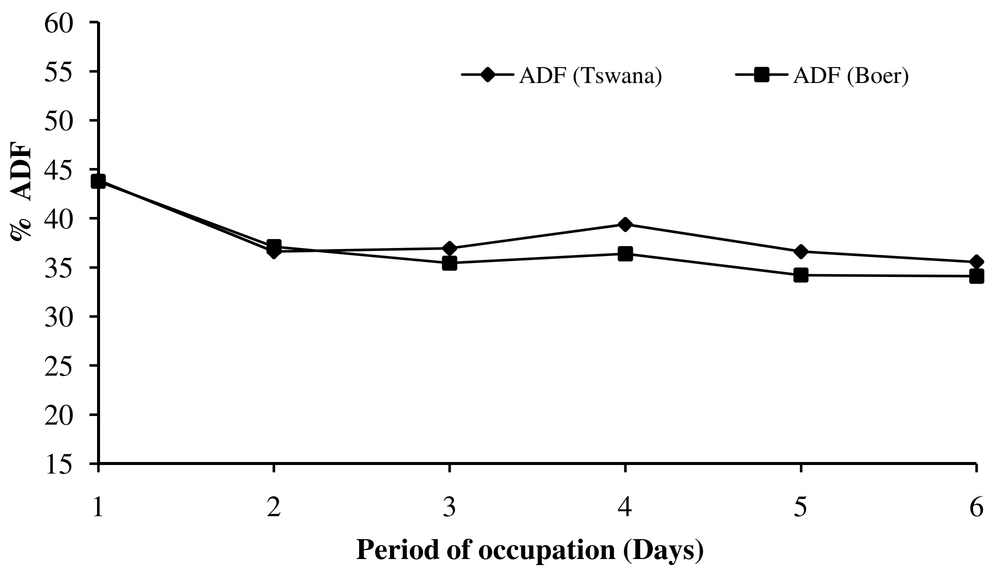

Figure 5.6. ADF content of diets selected by free ranging Tswana and Boer goats during the hot-wet season

5.4.4. Effect of season, breed, time of the day and period of occupation on the acid detergent lignin (ADL) content of forages selected by goats

The average ADL content of diets selected by goats, pooled over treatments did not differ significantly (P>0.05) between the cold-dry season (18.0 % SE = 0.52) and the hot-wet season (19.5 % SE = 0.52) as shown in Table 5.1. There was a significant difference (P=0.001) found between Tswana and Boer goats regarding the ADL content of selected forages (20.0 % and 17.5 % SE = 0.52 respectively). Regardless of breed and season, there were diurnal variations (P=0.01) in the ADL content of forages selected by goats. Goats selected forages with a lower ADL content both during midday and the afternoon while forages with higher ADL content were selected in the morning. There were also significant differences (P<0.0001) in the ADL content of forages selected by goats on different observation days. The ADL content of forages selected by Tswana and Boer goats during the period of occupation of a grazing/browsing camp did not differ significantly (P>0.05) during the cold-dry season as shown in Table 5.3 and graphically illustrated in Figure 5.7. However, during the hot-wet season there was a significant difference (P=0.004) in ADL content of forages selected by goats with advancing period of occupation of a grazing/browsing camp as shown in Table 5.4 and graphically illustrated in Figure 5.8.

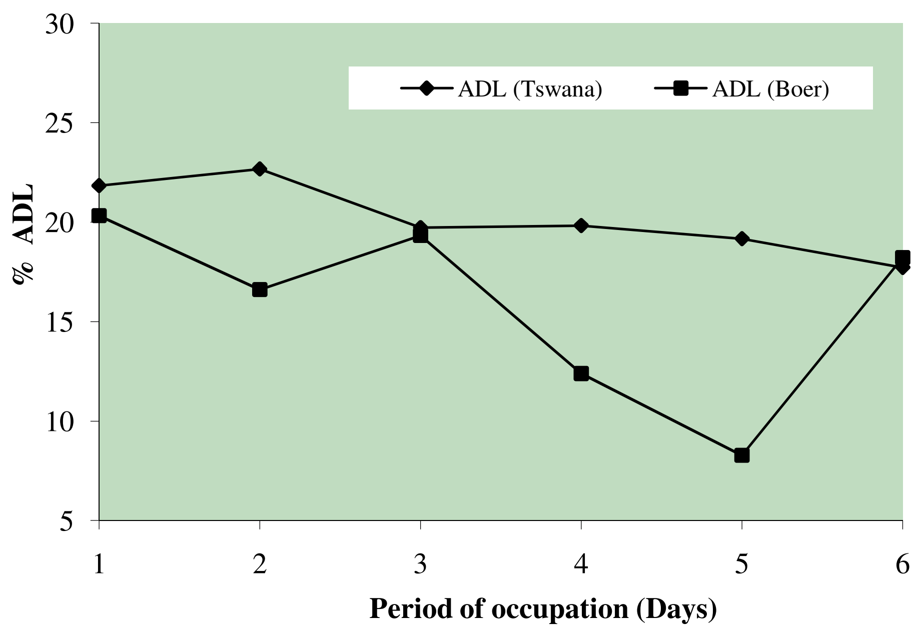

Figure 5.7. ADL content of diets selected by free ranging Tswana and Boer goats during the cold-dry season

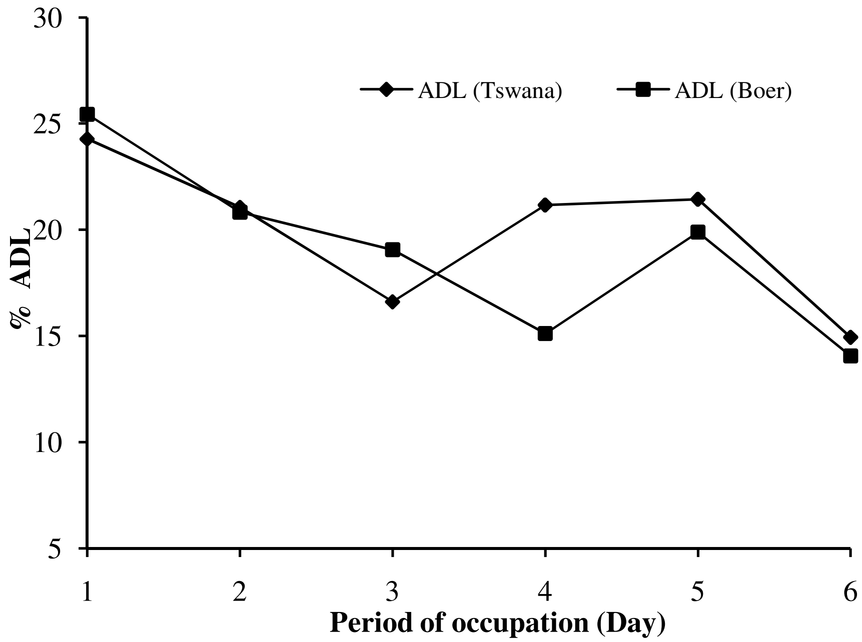

Figure 5.8. ADL content of diets selected by free ranging Tswana and Boer goats during the hot-wet season

5.5. Discussion

The nutrient content of the diet selected by free ranging Tswana and Boer goats varied substantially over seasons. The variation occurred in spite of the large seasonal differences in percentage grass and bush selected by goats. With the wide range of forage plants available to goats, including evergreen species, it is expected that these animals should be able to compensate to a very large degree for seasonal changes in the chemical composition of plants; especially as camps were stocked according to their carrying capacities. During most of the year the foliage of many woody plants has a protein content which is appreciably higher than that of the grasses, even after senescence and death. Otsyina & McKell (1985) showed browse to be richer in protein and certain minerals in the dry season. This is when browse species are the most valuable feed used by livestock. The ranges of NDF, ADF and ADL were comparable to earlier reports by Mogorosi (2000) who found goats to select diets with 45.8-51.1 % NDF, 30.4-31.4 % ADF and 12.5-21.6 % ADL. Seasonal variations in these constituents probably occurred as a result of differences in environmental conditions such as rainfall, temperature and relative humidity (Akkasaeng *et al*, 1989). Ott *et al*. (2004) found a decline in rainfall led to a decline in browse foliage production, which can also be a reason for the decline found in this study.

Crude protein levels reported in this study (5-9 %) were lower than those reported by Mogorosi (2000) in diets of free ranging Boer goats (12-17 %) but comparable to those obtained by Njwe *et al*., (1995) in a study on nutritive value of diets selected by West African dwarf goats (11-12 %) in central Nigeria. The seasonal fluctuations in crude protein contents may have been induced by the the hot-wet season (177 mm) precipitations and also by the high percentage grass (67 %) and low percent bush (37 %) in forages goats selected. Low precipitations during the cold-dry season (84 mm) led to a decline in crude protein resulting in levels that can be regarded as a protein deficiency. Normally the dietary crude protein is greater in the wet versus the dry season (Kronberg & Malecheck, 1997: Kawas *et al*., 2010). The higher crude protein of the diet during the hot-wet season is an expected phenomenon due to the availability of new growth in both the grass and woody components. Low protein contents in the cold-dry season are expected when leaves mature (Owen-Smith, 1988) and this is more pronounced in deciduous, rather than evergreen species. Experiments from the Eastern Cape Province indicate a seasonal tendency of crude protein to increase during spring, decrease in autumn and reach a minimum during the cold-dry season (Trollope, 1981). The 7.5 % CP level is considered as an adequate forage quality threshold, because it falls within the range of values for maintenance of goats (NRC, 1981). Therefore during the cold-dry season, both Tswana and Boer goats selected diets with insufficient crude protein to meet their maintenance requirements, indicating that protein supplementation is required. With the availability of evergreen bush, it is surprising that goats allocated a maximum of only 54 % of their feeding time to browsing activities during the cold-dry season. For goats to derive maximum nutritional benefit of browse available in the fodder banks, they should be able to select as much of browse as possible (Njwe *et al*, 1995). During both seasons, camps had stocking rates of 16 goats ha^{-1}, since any increase in the number of goats ha^{-1} beyond this capacity would have resulted in a decline in the proportion of browse in the diet. It is however evident that during the cold-dry season as the feed supply declined in quality and quantity, the stocking density should have been adjusted, particularly during the study period because the the cold-dry season was very dry.

In the cold-dry season when the quality of the grass is expected to deteriorate, it is surprising that the grass consumption (54 %) was higher than the browse consumption (46 %). This is probably due to the availability of large amounts of browse (evergreen and deciduous bush species) during the hot-wet season, but the supply was limited to only the evergreen species during the cold-dry season. The other reason may be that as feed supply was depleted in the cold-dry season, goats supplemented their diet with grasses to obtain enough dry matter. The high grass consumption during the cold-dry season resulted in a low crude protein content of the diet selected by goats, as crude protein in grasses reaches a minimum during the cold-dry season. Therefore, during the cold-dry season the use of forages from woody-plant species as a protein supplement can be an alternative strategy that perhaps has not been given adequate research and development attention (Ramirez, 1999).

Higher concentrations of CP were also observed during the early days of sampling in this study, followed by a decrease in CP during the later observation days but only during the cold-dry season. The reason for this is that goats consumed more bush when they first entered the camp and with advancing period of occupation switched to grazing. The significant decrease in CP content of diets selected by goats over time is evidence of the gradual fall in the quality of the foliage available to animals. Grazing animals tend to select the most digestible and nutritious species first before turning to less desirable species or plant parts (Njwe *et al.*, 1995). It has been demonstrated that diet selection is affected by protein levels in available plants (Nyamangara & Ndlovu, 1995; Dziba *et al*., 2003). Studies have already shown that browse generally has higher protein (Taylor & Kothman, 1990; Kadzere, 1995; Owen-Smith, 1997) and mineral contents (Otsyina & McKell 1985; Kadzere, 1995) compared to tropical grasses. During the hot-wet season the CP levels did not follow the trend found by Raats (1997), and this is probably because bush consumption was constantly high throughout the period of stay in the camp. Higher bush consumption resulted in higher CP levels in diets selected by both Tswana and Boer goats during the hot-wet season.

The NDF content ranged from 48.2 % in the cold-dry season to 53.8 % in the hot-wet season compared to a range of (57-59 %) in a study by Njwe *et al*., (1995) with African dwarf goats in Nigeria. The NDF (49.6 %) values obtained in a study by Cerrillo *et al*., (2006) with Spanish goats browsing a thorn shrubland in North Mexico are also comparable to the results of this study. Diets with a cell wall content of 45-55 % are acceptable source of energy for range ruminants (Johnson & de Oliveira, 1989). Thus, values obtained in this study (mean = 51 %)

may indicate an adequate source of energy to sustain productivity of goats. Crude protein and NDF concentrations of the diet were found to be affected by season, stocking rate and period of occupation (Webber *et al*., 1996; Raats, 1997). These researchers found CP in the diet to be significantly higher and NDF significantly lower during the initial days of occupation of a camp compared to the subsequent period of occupation. This corresponds with lower levels of NDF during the first day of sampling in the present study, followed by an increase in NDF during the later observation days, but only during the hot-wet season. The probable reason for this is an increase in the amount of bush consumed with advancing period of occupation during the hot-wet season. During the cold-dry season the NDF levels did not follow the trend found by Raats (1997). This is probably because the amount of bush consumed decreased with advancing period of occupation. The NDF content of selected diets seems to be positively correlated to browse consumption.

Against expectations, the ADF content of the diet was higher in the hot-wet season than in the cold-dry season. This may be due to the higher browse component in the diet during the hot-wet season. High temperatures and solar radiation during the hot-wet season increase fibre fractions of plants because of thickened cell walls (Wilson *et al*., 1991) and enhanced lignin synthesis (Buxton & Fales, 1994; Ngwa *et al*., 2000). The ADF (37.5 %) value obtained in a study by Cerrillo *et al*., (2006) with Spanish goats browsing a thorn shrubland in North Mexico are comparable to the results of this study.

Dietary lignin (mean = 19 %) did not vary between seasons but goats selected forages higher in lignin content in the morning than midday and afternoon. This was probably because forages selected in the morning had higher browse content than those selected at midday and in the afternoon. It is known that twigs from browse contain a high level of lignin.

5.6. Conclusions

In diets selected by goats CP, NDF and ADF were all affected by climatic conditions with the exception of ADL. Goats selected diets higher in CP, NDF and ADF during the hot-wet season compared to the cold-dry season. However, the type of breed did not have any effect on the nutrient content of diets selected as Tswana and Boer goats selected diets not differing significantly in nutrient content within a season. Period of occupation of a camp had an effect on the nutrient content of diets selected by free ranging Tswana and Boer goats. Nutrient content of selected diets decreased in quality with advancing period of occupation of a camp. Dietary CP was adequate to meet goat requirements only in the hot-wet season. During the cold-dry season, both Tswana and Boer goats selected diets with insufficient crude protein to meet their maintenance requirements. A regime of CP supplementation must be considered during the cold-dry season.

CHAPTER 6

IN SACCO DRY MATTER AND CRUDE PROTEIN DEGRADATION OF WOODY PLANT SPECIES IN TSWANA AND BOER GOATS

6.1. Introduction

In desert and tropical environments, feed resources are restricted in quantity and quality (Sheridan *et al*., 2003). Seasonal fluctuations in forage availability and quality are one of the main causes of nutritional stress that limit animal production in these regions (Kawas *et al*., 1999). Kawas *et al*. (2010) states that forage availability may be as limiting as forage quality to goat performance. The intake of animals on the natural vegetation is fairly high during the growing season as the plants produce fresh and lush leaves and stem that could be grazed and utilized accompanied by reasonable body weight gains and general performance. As the plants mature, all their quality indices depreciate rapidly aggravated by the approaching dry season. Animal intake, digestibility and other quality variables also progressively decrease (Anele *et al*., 2009).

Trees and shrubs have been found to play an important role in providing fodder for ruminants in these parts of the world (Fall-Toure *et al*., 1993; Tolera *et al*., 1997; Kawas *et al*., 2010; Camacho *et al*., 2010). Most browse species have an advantage of maintaining their greenness and nutritive value throughout the dry season when grasses dry up and deteriorate both in quality and quantity. Browse is generally richer in protein and minerals (Le Houeron, 1980; Ørskov, 1993; Kadzere, 1995; Owen-Smith, 1997; Alonso-Diaz *et al*., 2010) and thus has the potential to be an inexpensive, locally produced protein supplement that plays an important role in the nutrition of grazing animals (Meuret *et al*., 1990; Salem *et al*., 2006).

The performance of herbivores when grazing, thus depends on forage digestibility and intake (Ramirez *et al*., 2000; Decruyenaere *et al*., 2009; Fraser *et al*., 2009). Moreover, forage intake is related to fibre digestibility because intake is reduced when fibre is increased in the digestive tract (Mertens, 1993). Rate of digestion provides an important measure of forage quality because intake of forages having rapid rates of digestion is greater than that for forages with slower rates of digestion but similar total digestibility (Holechek *et al*., 1982).

Since the rumen is the primary site of digestion of forages, it is important to monitor their degradation kinetics. This can be achieved by using *in sacco* technique which is quicker and cheaper than whole animal studies. Important characteristics of digestion in the rumen with regard to forages are: effective degradability, lag time, rate of digestion and the amount of digestible fibre (Singh *et al*., 1989; Larbi *et al*., 1997). Rumen degradation is thus regarded as a major descriptor of forage quality (Ørskov and McDonald, 1979). It is useful in ranking trees and shrubs in terms of nutritive value (Larbi *et al*., 1994) and for comparing the digestive capabilities of important characteristics of forages (Migongo-Bake, 1992; Singh *et al*., 1989).

The objective of this study was to estimate *in sacco* degradation characteristics of dry matter and crude protein in woody plant species, which were highly preferred and selected by goats during the cold-dry season (*Scutia myrtinus*, *Olea africana*, *Grewia occidentalis*) and the hot-wet season (*Scutia myrtinus*, *Acacia karroo*, *Rhus refracta*), when incubated in the rumen of the Tswana and Boer goats.

6.2. Materials and methods

6.2.1. Experimental goats

Six wethers (3 Tswana and 3 Boer) each ± 2 years old, with mean body weight of (Tswana ± 37 kg; Boer 36 kg) and each permanently fitted with a rumen cannulae were individually housed in metabolic crates. Goats had a 7 day adaptation period to the diet which was made of 50 % lucerne hay and 50 % of the woody plant species under investigation. Two kilograms of the diet was given to each goat at both 0800h and 1600h. Water was available *ad libitum* and goats had free access to a mineralised lick.

6.2.2. Experimental woody plants

The terminal shoot, made up of young leaves and stems < 6mm in diameter of the three most preferred woody plant species in the cold-dry season (*Scutia myrtina, Olea africana, Grewia occidentalis*) and the hot-wet season (*Scutia myrtina, Rhus refracta, Acacia karroo*) were harvested from University of Fort Hare Honeydale Research Farm near Alice, in the Eastern Cape Province of South Africa ($32^0$49′S, $26^0$54′E). Samples were collected from un-browsed bush species (6 trees per species to eliminate variation in the concentration of compounds among individual trees). The harvested bush samples were dried at 60 °C for 48 hours to determine DM and milled through a 2 mm sieve. All samples were analysed for nitrogen (N) as outlined by the Kjeldahl method (AOAC, 1990) and crude protein (CP) calculated as N x 6.25. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were analysed using the filter bag technique (ANKOM Technology). Subsamples of the milled bush samples were used to determine rumen degradability.

6.2.3. Experimental procedures

The ruminal degradability of the three most preferred woody plant species by goats, during the cold-dry season (*G. occidentalis, O. africana* and *S. myrtinus*) and the hot-wet season (*A. karroo, R. refracta* and *S. myrtinus),* was measured in situ, using the nylon bag technique described by Ørskov *et al*. (1980). Samples (5 g DM) of each of the most preferred bush species were placed in nylon bags made of a permeable synthetic fabric (size 5 cm x 10 cm and pore size 45 µm). The bags were incubated in the rumen of 3 Tswana and 3 Boer goats for 72, 48, 36, 24, 16, 8, 4, 2 or 0 hours before removal at a common time. Upon removal from the rumen, bags were washed in cold running tap water while rubbing gently between thumb and fingers until the water became clear. Zero time disappearances (washing losses) were obtained by washing un-incubated bags in a similar fashion. Bags were dried in an oven at 60 °C for 48 hours and weighed to determine the dry weight of the incubation residues. The residual samples were removed from each bag and analysed for total nitrogen using the Kjeldahl method (AOAC, 1990) and crude protein (CP) calculated as N x 6.25. The percentage disappearance of dry matter and nitrogen was calculated from their respective amounts remaining after incubation in the rumen. Disappearance was assumed to be due to degradation in the rumen.

Dry matter disappearance was calculated using the formula (Jansen *et al*., 2007):

$$\text{DM disappearance (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

The three browse species within a season were compared in terms of disappearance of DM and CP from the bags incubated in the rumen of Tswana and Boer goats.

6.3. Statistical analyses

Disappearance data for DM and CP were fitted for each goat to the exponential model of Ørskov & Macdonald, (1979):

$P = a + b(1 - e^{-ct})$

where: P is the disappearance of nutrients during time *t*;

a the soluble nutrients fraction which is rapidly washed out of the bags and is assumed to be completely degradable or is an intercept representing the portion of DM and CP solubilised at initiation of incubation (time 0);

b the proportion of DM and CP potentially degradable by micro-organisms (slowly degradable fraction);

c is the degradation rate of fraction *b* per hour (% per hour) or rate constant of fraction *b*;

t is the incubation time (h).

The nonlinear parameters *a*, *b* and *c* were estimated using PROC NLIN (SAS 2003). Correlation analyses were used to investigate relationships between dry matter, crude protein degradation, chemical composition and time of incubation of the woody plant species. Differences in significant terms were determined using least significant differences ($LSD_{0.05}$) by SAS (2003) for all analyses.

6.3. Results

6.3.1. Chemical composition of the woody plant species

The chemical composition of the woody plant species used for *in sacco* degradation during the cold-dry season and the hot-wet season is presented in Table 6.1 and Table 6.2 respectively.

Table 6.1. Chemical composition of the woody plant species used for *in sacco* digestion during the cold-dry season (% DM)

Nutrient	Woody plant species		
	Grewia occidentalis	**Olea Africana**	**Scutia myrtina**
DM	95.3	95.1	95.6
CP	10.0	7.0	8.0
NDF	59.0	45.0	58.0
ADF	28.0	33.0	54.0
ADL	21.0	20.0	38.0

Dry matter (DM), Crude Protein (CP), Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF), Acid Detergent Lignin (ADL)

Table 6.2. Chemical composition of the woody plant species used for *in sacco* digestion during the hot-wet season (% DM).

Nutrient	Woody plant species		
	Acacia karroo	**Rhus refracta**	**Scutia. Myrtina**
DM	93.8	93.7	94.4
CP	18.0	8.0	10.0
NDF	48.0	46.0	42.0
ADF	31.0	29.0	34.0
ADL	25.0	20.0	25.0

Dry matter (DM), Crude Protein (CP), Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF), Acid Detergent Lignin (ADL)

The dry matter content of the same samples taken from woody plant species ranged from 93.7 % in the hot-wet season to 95.6 % in the cold-dry season but did not vary significantly within each season. The crude protein content was significantly different between browse species. During the cold-dry season the crude protein content was lower, ranging from 7 % to10 % and higher in the hot-wet season, ranging from 10 % to 18 %. Across seasons, *Acacia karroo* had the highest crude protein (18%) while *O. africana* had the lowest (7 %). The NDF content of the woody plant species ranged from 42 to 59 % while the ADF content ranged from 29% to 54 %. The lignin content ranged from 20 to 38 %.

6.4.2. Ruminal dry matter degradation during the cold-dry season

Regardless of the breed, the nylon bag incubation revealed large differences in the rumen degradability of DM the three woody plant species during the cold-dry season. The disappearance of DM of woody plant species from the rumen are presented in Figure 6.1. *Olea africana* exhibited rapid rumen degradability of DM, about 63 % of the DM disappearing within 24 hours of incubation. On the other hand only 52 % DM of *G. occidentalis* disappeared within 24 hours of incubation. The disappearance of *S. myrtina* dry matter from the nylon bags was the slowest, with only 30 % disappearing within 24 hours of incubation. After 72 hours of incubation, 75 % DM of *O. africana*, 69 % DMD of *G. occidentalis* and only 37 % DM of *S. myrtina* had disappeared from the nylon bags.

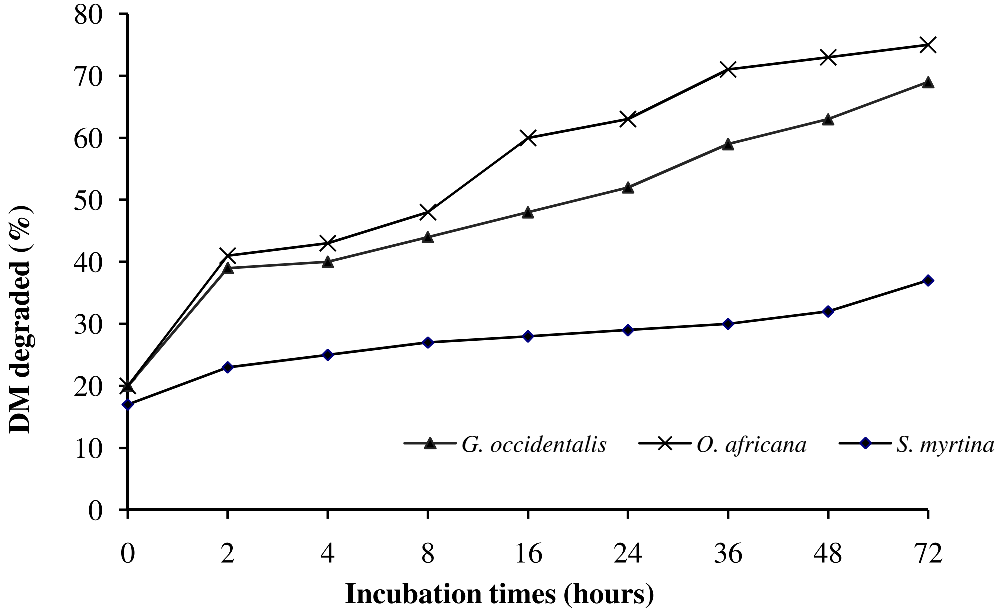

Figure 6.1. *In sacco* dry matter degradation of *G. occidentalis*, *O. africana* and *S. myrtina* during the cold-dry season

A higher percentage of *G. occidentalis* dry matter disappeared from the rumen of Boer goats compared to Tswana goats both at 24 hours (Boer 55 %; Tswana 49 %) and 48 hours (Boer 67 %; Tswana 60 %) of incubation as shown in Table 6.3. *Olea africana* was however degraded to the same extent by both breeds after 24 hours of incubation (Boer 63 %; Tswana 63 %). *Scutia myrtina* was the slowest degrading woody plant species and was also degraded to almost the same extent by both breed after 24 hours (Boer 30 %; Tswana 29 %) and 48 hours (Boer 32 %; Tswana 33 %) of incubation. After 72 hours of incubating *O. africana*, 78 % of it disappeared from the rumen of Tswana goats while 74 % disappeared from the rumen of Boer goats. Boer goats however had a higher DM % disappearance of both *G. occidentalis* (Boer 73 %; Tswana 66 %) and *S. myrtina* (Boer 39 %; Tswana 36 %) after 72 hours of incubation.

Table 6.3. Estimated dry matter degradability parameters of *Grewia occidentalis, Olea africana and Scutia myrtina* during the cold-dry season

Item	**(%) DRY MATTER DISAPPEARANCE**					
	Grewia occidentalis		***Olea africana***		***Scutia myrtina***	
Time (h)of incubation	Tswana	Boer	Tswana	Boer	Tswana	Boer
0	20	20	20	20	17	17
2	36	42	40	43	21	26
4	38	43	42	45	23	27
8	41	47	43	53	26	29
16	44	52	60	61	27	29
24	49	55	63	63	29	30
36	56	63	72	70	30	30
48	60	67	74	71	33	32
72	65	74	78	73	36	38
DEGRADATION RATE CONSTANTS (±SE)						
A	28.2^{b} ± 0.01	30.9^{a} ± 0.01	27.0^{c} ± 0.01	25.2^{d} ± 0.01	19.4^{f} ± 0.01	22.8^{e} ± 0.01
B	37.3^{d} ± 0.03	41.9^{c} ± 0.03	50.1^{a} ± 0.03	44.16^{b} ± 0.03	16.3^{e} ± 0.03	14.1^{f} ± 0.03
a + b	65.8^{d} ± 0.07	72.8^{b} ± 0.07	77.7^{a} ± 0.07	69.4 ^{c} ± 0.07	35.7^{f} ± 0.07	39.0^{e} ± 0.07
C	0.04^{b} ± 0.01	0.05 ^{b} ± 0.01	0.06 ^{b} ± 0.01	0.14 ^{a} ± 0.01	0.04^{b} ± 0.01	0.03^{b} ± 0.01

a = Fraction of DM (%) lost during washing; *b* = Fraction of DM (%) degraded; *a* + *b* = Fraction of DM (%) potentially degraded; *c* = Rate of degradation of DM (h^{-1}); SE = Standard error, *n* = 3
Means in a row with different superscripts differ significantly (P < 0.05)

Constants for the ruminal degradation of *G. occidentalis* (*a* = 30.9 %; b = 41.9 % and *a+b* = 72.8 %) for Boer goats were significantly higher (P<0.0001) than those for Tswana goats (*a* = 28.2 %; *b* = 37.3 %; *a+b* = 65.8 %). However, the rate of degradation of *G. occidentalis* did not differ significantly (P>0.05) between the Tswana (0.04% h^{-1}) and Boer goats (0.05 % h^{-1}). On the other hand, the ruminal degradation constants (*a*, *b* and *a+b*) for *O. africana* were significantly higher (P<0.0001) for Tswana goats (*a* = 27.0 %; *b* = 50.1 % and *a+b* = 77.7 %) compared to Boer goats (*a* = 25.2 %; *b* = 44.2 % and *a+b* = 69.4 %). However, the rate of degradation, as reflected by the constant (*c*), for *O. africana* and for *S. myrtina* was significantly higher (P<0.0001) for Boer (0.14 % $h^{-1}$and 0.02 % h^{-1}) compared to Tswana (0.06 % $h^{-1}$and 0.01 % h^{-1}) goats. The fraction lost during washing (*a*), and the potentially degraded fraction (*a+b*) of dry matter percentage for *S. myrtina* were significantly higher (P<0.0001) for Boer (*a* = 22.8 %; *a+b* = 39.0 %) compared to Tswana (*a* = 19.4 %; *a+b* = 35.7 %) goats. However, the rate of degradation (*c*) of *S. myrtina* did not differ significantly (P<0.05) between the two breeds.

6.4.3. Ruminal crude protein degradation during the cold-dry season

Across breed, the nylon bag incubation revealed large differences in the rumen degradability of crude protein of the three woody plant species during the cold-dry season (Figure 6.2).

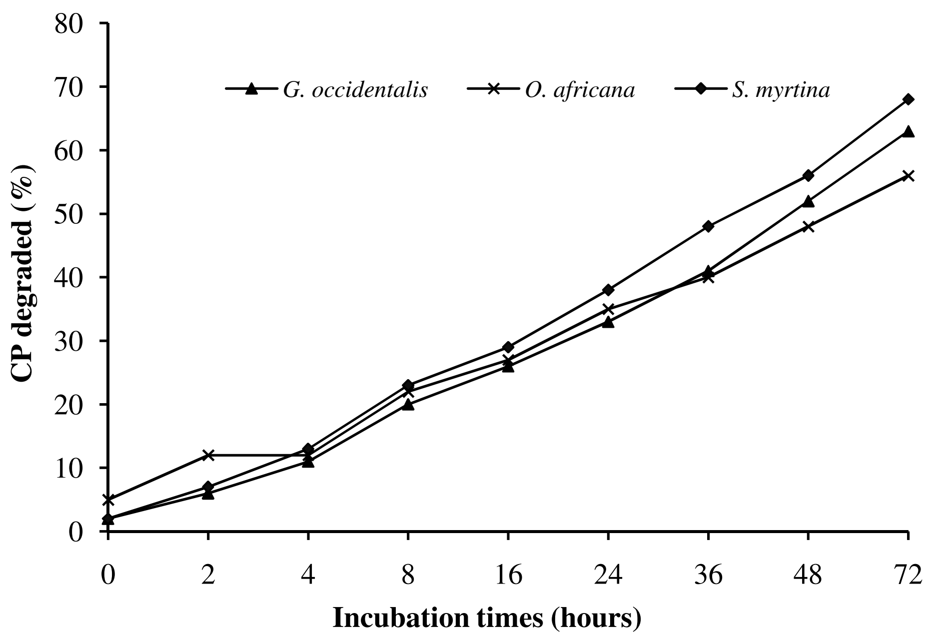

Figure 6.2. *In sacco* crude protein degradation of *G. occidentalis*, *O. africana* and *S. myrtina* during the cold-dry season

Rumen crude protein degradability of *S. myrtina* was greater than that of *G. occidentalis and O. africana*, but all increased with increasing rumen incubation times. *S. myrtina* exhibited rapid rumen degradability of CP, about 38 % of the CP disappearing within 24 hours of incubation compared to *O. africana* (35 %) and *G. occidentalis* (33 %). Crude protein degradability after 48 hours of incubation was still higher for *S. myrtina* (56 %) compared to *G. occidentalis* (52 %) and *O. africana* (48 %).

Boer goats digested more CP from the sample of *O. Africana* during the *in sacco* trial than the Tswana goats, both at 24 hours (Boer 40 %; Tswana 30 %) and 48 hours of incubation (Boer 52 %; Tswana 44 %) as shown in Table 6.4. Both breeds however had similar fractions of CP digested from the *S. myrtina* sample after 24 hours (38 %) of incubation. Similarly the CP content of *G. occidentalis* was degraded to the same extent by both breeds after 24 hours of incubation (33 %). After 48 hours of incubation, the crude protein in the *S. myrtina* sample was degraded more by Tswana goats (58 %) compared to Boer goats (54 %). Crude protein content of *G. occidentalis* was degraded to the same extend by both breeds (52 %) after 48 hours of incubation. Boer goats however, degraded crude protein of *O. africana* to a greater extent than the Tswana goats (44 %) after 48 hours of incubation as shown in Figure 6.3.

Table 6.4. Estimated crude protein degradability parameters for *Grewia occidentalis*, *Olea africana* and *Scutia myrtina* during the cold-dry season

Item	**(%) CRUDE PROTEIN DISAPPEARANCE**					
	Grewia occidentalis		***Olea africana***		***Scutia myrtina***	
Time (h)of Incubation	Tswana	Boer	Tswana	Boer	Tswana	Boer
0	2	2	5	5	2	2
2	7	4	11	12	8	4
4	11	11	11	12	13	13
8	19	22	19	24	25	21
16	30	22	26	28	25	33
24	33	33	30	40	38	38
36	41	41	37	44	50	46
48	52	52	44	52	58	54
72	63	63	52	61	69	67
DEGRADATION RATE CONSTANTS (±SE)						
a	$4.3^{c} \pm 0.011$	$3.8^{d} \pm 0.011$	$7.0^{a} \pm 0.011$	$7.0^{a} \pm 0.011$	$4.9^{b} \pm 0.011$	$3.2^{e} \pm 0.011$
b	$70.5^{c} \pm 0.025$	$77.9^{b} \pm 0.025$	$52.8^{f} \pm 0.025$	$59.5^{e} \pm 0.025$	$78.4^{a} \pm 0.025$	$69.1^{d} \pm 0.025$
a + b	$74.9^{c} \pm 0.004$	$81.7^{b} \pm 0.004$	$59.9^{f} \pm 0.004$	$66.6^{e} \pm 0.004$	$83.3^{a} \pm 0.004$	$72.3^{d} \pm 0.004$
c	$0.02^{a} \pm 0.009$	$0.02^{a} \pm 0.009$	$0.03^{a} \pm 0.009$	$0.03^{a} \pm 0.009$	$0.02^{a} \pm 0.009$	$0.03^{a} \pm 0.009$

a = Fraction of DM (%) lost during washing; *b* = Fraction of DM (%) degraded; *a* + *b* = Fraction of DM (%) potentially degraded; *c* = Rate of degradation of DM (h^{-1}); SE = Standard error, *n* = 3
Means in a row with different superscripts differ significantly (P < 0.05)

The ruminal degradation constant (*a*) for *O. africana* did not differ significantly (P>0.05) between the Tswana (7.0 %) and the Boer (7.0 %) goats. However, the ruminal degradation constant (*a*) differed significantly (P<0.0001) between breeds for *G. occidentalis* (Tswana 4.3 %; Boer 3.8 %) and *S. myrtina* (Tswana 4.9 %; Boer 3.2 %). The fraction of crude protein from *S. myrtina* which was slowly degraded (*b*) was significantly higher (P<0.0001) for Tswana (78.4 %) compared to Boer (69.1 %) goats. The protein degradation constant (*b*) for both *G. occidentalis* and *O. africana* was however significantly higher (P<0.0001) in Boer goats (*G. occidentalis* 77.9 %; *O. africana* 59.5 %) compared to Tswana (*G. occidentalis* 70.5 %; *O. africana* 52.8 %). The rate of degradation (c h^{-1}) of the crude protein fraction for the three woody plant species, by Tswana and Boer goats did not differ significantly (P>0.05). Dry matter and crude protein degradation of *G. occidentalis*, *O. Africana* and *S. myrtina* are graphically illustrated in Figures 5.3, 5.4 and 5.5, respectively.

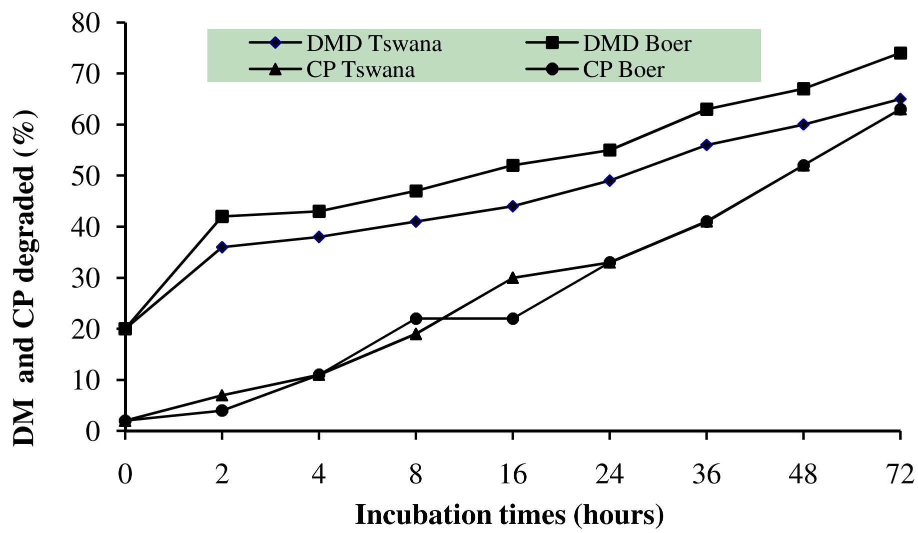

Figure 6.3. *In sacco* DM and CP degradation of *G. occidentalis* by Tswana and Boer goats during the cold-dry season

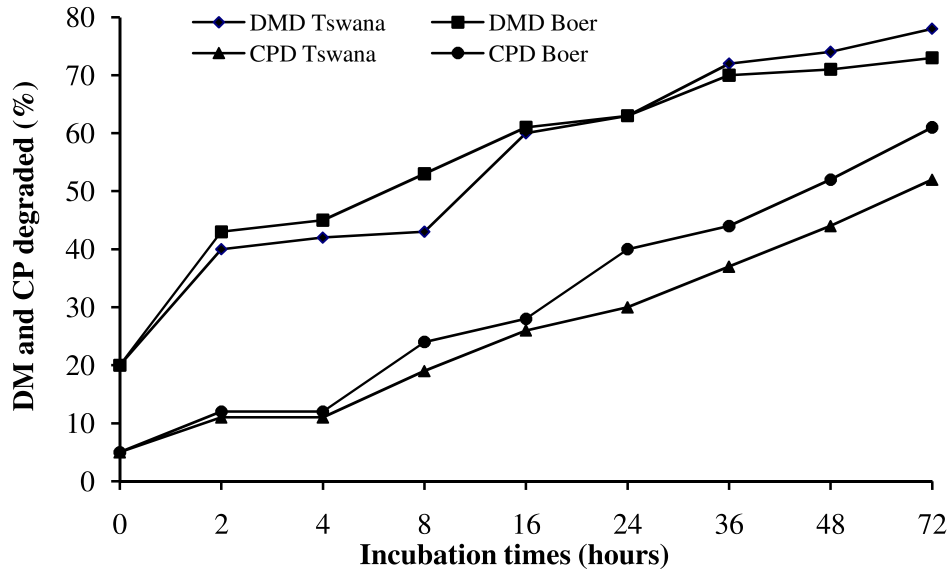

Figure 6.4. *In sacco* dry matter and crude protein degradation of *O. africana* by Tswana and Boer goats during the cold-dry season

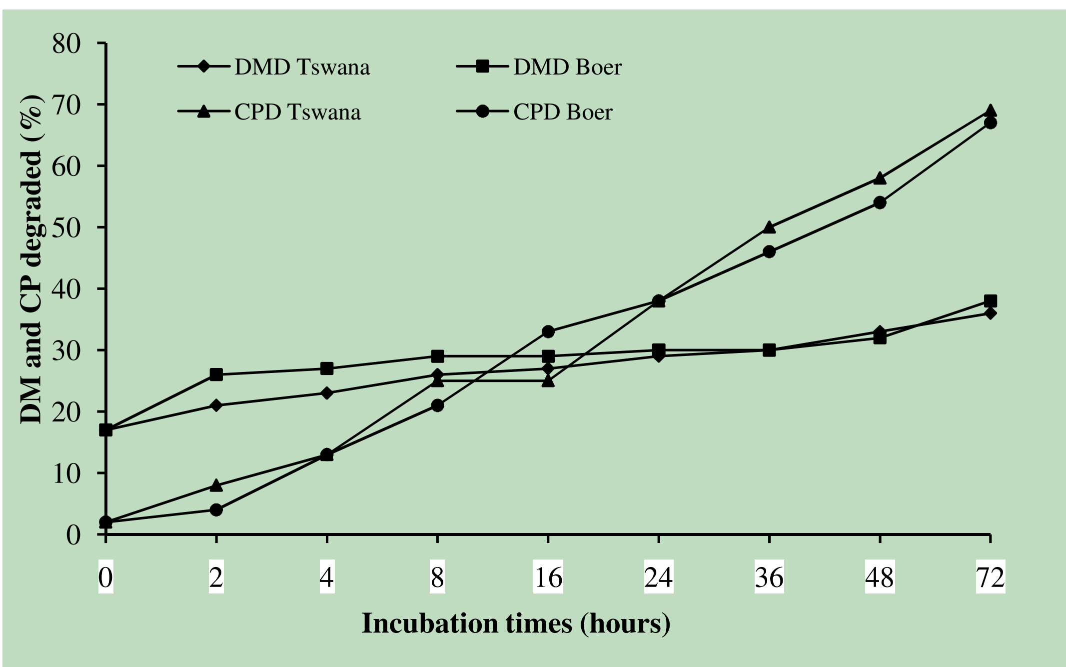

Figure 6.5. *In sacco* DM and CP degradation of *S. myrtina* by Tswana and Boer goats during the cold-dry season

6.4.4. Relationships between DMD, CPD and incubation time in Tswana and Boer goats during the cold-dry season

Dry matter and crude protein degradation for *S. myrtina* were highly correlated with the time of incubation in both Tswana (r^2=0.93; P=0.0003 and r^2=0.97 P<0.0001 respectively) and Boer goats (r^2=0.83; P=0.01; r^2=0.96; P<0.0001, respectively). There was also a strong positive correlation between DMD and CPD (Tswana r^2=0.98; P<0.0001; Boer r^2=0.87; P=0.002). *G. occidentalis* showed strong positive correlation of both DMD (Tswana r^2=0.91 P=0.001; Boer r^2=0.89 P=0.0001) and CPD (Tswana r^2=0.97; P<0.0001; Boer r^2=0.97; P<0.0001) with time of incubation in the rumen. Dry matter degradation strongly correlated with CPD (Tswana r^2=0.96; P<0.001; Boer r^2=0.93; P=0.0003). Similarly for *O. africana*, there was a strong positive correlation of both DMD (Tswana r^2=0.88 P=0.002; Boer r^2=0.80; P=0.01) and CPD (Tswana r^2=0.97; P<0.0001; Boer r^2=0.96; P<0.0001) with time of incubation in the rumen. There was also a strong positive correlation between DMD and CPD (Tswana r^2=0.95; P<0.0001; Boer r^2=0.92; P=0.001). Equations for predicting DMD and CPD of woody plant species in Tswana and Boer goats during the cold-dry season and the hot-wet season are shown in Table 6.5.

Table 6.5. Equations predicting dry matter and crude protein degradabilies during the cold-dry season for Tswana goats and Boer goats

BREED	SPECIES	EQUATION	r^2
Tswana	*Scutia myrtina*	Y = 18.3 - 0.07 TIME + 0.32 CPD	0.96
	Grewia occidentalis	Y = 25.3 - 0.21 TIME + 0.88 CPD	0.93
	Olea africana	Y = 14.9 - 0.64 TIME + 2.09 CPD	0.95
Boer	*Scutia myrtina*	Y = 21.9 - 0.01 TIME + 0.23 CPD	0.76
	Grewia occidentalis	Y = 30.1 - 0.22 TIME + 0.96 CPD	0.87
	Olea africana	Y = 22.3 - 0.59 TIME + 1.52 CPD	0.90
Tswana	*Scutia myrtina*	Y = - 37.9 + 0.42 TIME + 2.24 DMD	0.98
	Grewia occidentalis	Y = - 12.5 + 0.49 TIME + 0.65 DMD	0.98
	Olea africana	Y = - 3.4 + 0.37 TIME + 0.38 DMD	0.99
Boer	*Scutia myrtina*	Y = - 13.7 - 0.70 TIME + 0.98 DMD	0.94
	Grewia occidentalis	Y = - 8.0 + 0.60 TIME + 0.42 DMD	0.97
	Olea african	Y = - 6.9 + 0.49 TIME + 0.47 DMD	0.98

6.4.5. Ruminal dry matter degradation during the hot-wet season

The nylon bag incubation revealed large differences in the rumen degradability of DM of the three browse species (Figure 5.6) regardless of the animal species.

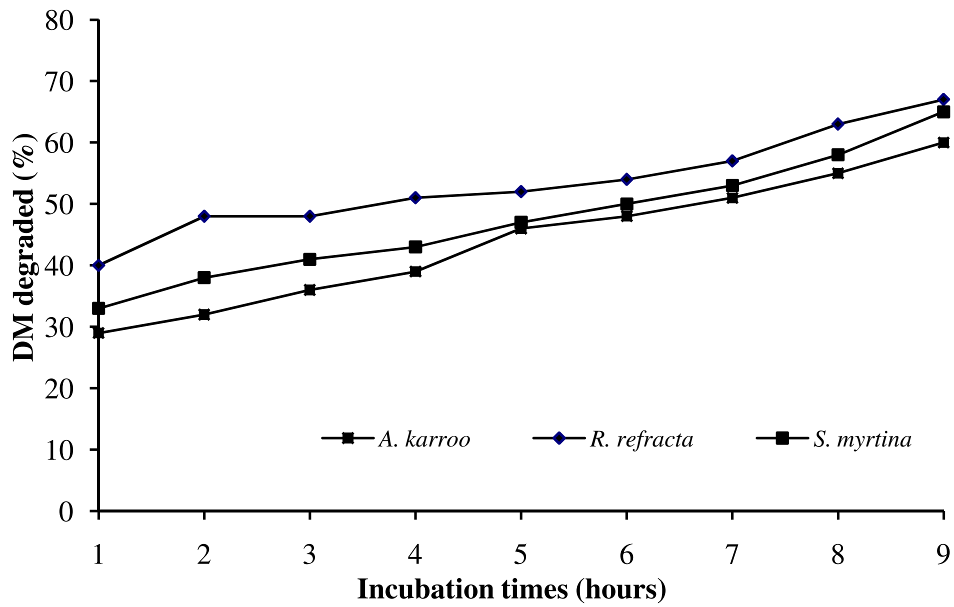

Figure 6.6. *In sacco* dry matter degradation of *A. karroo*, *R. refracta* and *S. myrtina* during the hot-wet season

Rumen dry matter degradabilities of *R. refracta* and *S. myrtina* were greater than that of *A. karroo* and increased with increasing rumen incubation times. *Rhus refracta* exhibited rapid rumen degradability of DM, with about 54 % of the DM disappearing within 24 hours. *Acacia karroo* and *S. myrtina* were degraded to almost the same extend (49 % and 50 % respectively) after 24 hours of incubation. Dry matter degradabilities of *A. karroo* and *S. myrtina* were only 55 % and 58 % respectively after 48 hours of incubation while that of *R. refracta* was 63 %. Though *R. refracta* exhibited rapid rumen degradation initially, its degradability dropped and between 24 and 48 hours of incubation was lower (only 4 % disappearing) compared to *A. karroo* (8 %) and *S. myrtina* (7 %).

A higher fraction of DM of *R. refracta* was degraded by Tswana goats than by the Boer goats, both at 24 hours (Boer 51 %; Tswana 57 %) and 48 hours of incubation (Boer 58 %; Tswana 68 %) as shown in Table 6.9 and graphically illustrated in Figure 6.6. Boer goats however, showed a higher fraction of DM of *S. myrtina* degraded both after 24 hours (Boer 51 %; Tswana 48 %)

and 48 hours of incubation (Boer 61 %; Tswana 55 %). *Acacia karroo* had the lowest fraction of DM degraded after 24 hours of incubation, with only 47 % and 50% degraded by Boer and Tswana goats respectively. After 48 hours of incubation, *A. karroo* was degraded to a greater extent by Boer goats (56 %) compared to Tswana goats (54 %).

Rhus refracta ruminal degradation constants (*a* = 45.6 %; *b* = 37.2 % and *a*+*b* = 82.8 %) for Boer goats were higher (P < 0.05) compared to those for Tswana goats (*a* = 43.4 %; *b* = 35.3 %; *a*+*b* = 78.7 %) as shown in Table 6.6. However, the rate of degradation of *R. refracta* was higher in Tswana (0.02 % h^{-1}) than Boer goats (0.01 % h^{-1}). Ruminal degradation constants (*a*, *b* and *a*+*b*) of both *S. myrtina* and *A. karroo* were higher for Tswana than for Boer goats. However, the rate of degradation constant (*c*) for *A. karroo* was similar for both breeds (0.04 % h^{-1}), while for S. myrtina, Boer goats (0.02 % h^{-1}) had a higher rate of degradation compared to Tswana goats (0.01 % h^{-1}).

Table 6.6. Estimated dry matter degradability parameters of *Acacia karroo, Rhus refracta* and *Scutia myrtina* during the hot-wet season

Item	**(%) DRY MATTER DISAPPEARANCE**					
	Grewia occidentalis		***Olea africana***		***Scutia myrtina***	
Time (h)of Incubation	Tswana	Boer	Tswana	Boer	Tswana	Boer
0	29	29	40	40	33	33
2	31	32	47	49	40	37
4	37	35	47	49	41	41
8	41	38	51	51	45	41
16	47	45	55	49	47	46
24	50	47	57	51	48	51
36	52	50	61	54	51	53
48	54	56	68	58	55	61
72	63	57	72	62	66	64
DEGRADATION RATE CONSTANTS (± SE)						
a	$30.4^{e} \pm 0.024$	$29.8^{f} \pm 0.024$	$43.4^{b} \pm 0.024$	$45.6^{a} \pm 0.024$	$38.0^{c} \pm 0.024$	$35.1^{d} \pm 0.024$
b	$31.1^{e} \pm 0.033$	$28.6^{f} \pm 0.033$	$35.3^{d} \pm 0.033$	$37.2^{b} \pm 0.033$	$50.2^{a} \pm 0.033$	$35.6^{c} \pm 0.033$
a + b	$61.4^{e} \pm 0.005$	$58.8^{f} \pm 0.005$	$78.7^{c} \pm 0.005$	$82.8^{b} \pm 0.005$	$88.2^{a} \pm 0.005$	$70.7^{d} \pm 0.005$
c	$0.04^{b} \pm 0.004$	$0.04^{b} \pm 0.004$	$0.02^{a} \pm 0.004$	$0.01^{a} \pm 0.004$	$0.01^{a} \pm 0.004$	$0.02^{a} \pm 0.004$

a = Fraction of DM (%) lost during washing; *b* = Fraction of DM (%) degraded; *a* + *b* = Fraction of DM (%) potentially degraded; *c* = Rate of degradation of DM (h^{-1}); SE = Standard error, *n* = 3
Means in a row with different superscripts differ significantly (P < 0.05)

6.4.6. Ruminal crude protein degradation during the hot-wet season

Regardless of the breed of goat, the nylon bag incubation revealed large differences in the rumen degradability of crude protein of the three browse species during the hot-wet season (Figure 6.7). Rumen CP degradabilities of *A. karroo* were greater than that of *R. refracta and S. myrtina* and increased with increasing rumen incubation times. *Acacia karroo* exhibited rapid rumen degradability of CP, about 41 % of the CP disappearing within 24 hours of incubation compared to *S. myrtina* (39 %) and *R. refracta* (31 %). Crude protein degradability after 48 hours of incubation were still higher for *A. karroo* (55 %) compared to *S. myrtina* (51 %) and *R. refracta* (44 %).

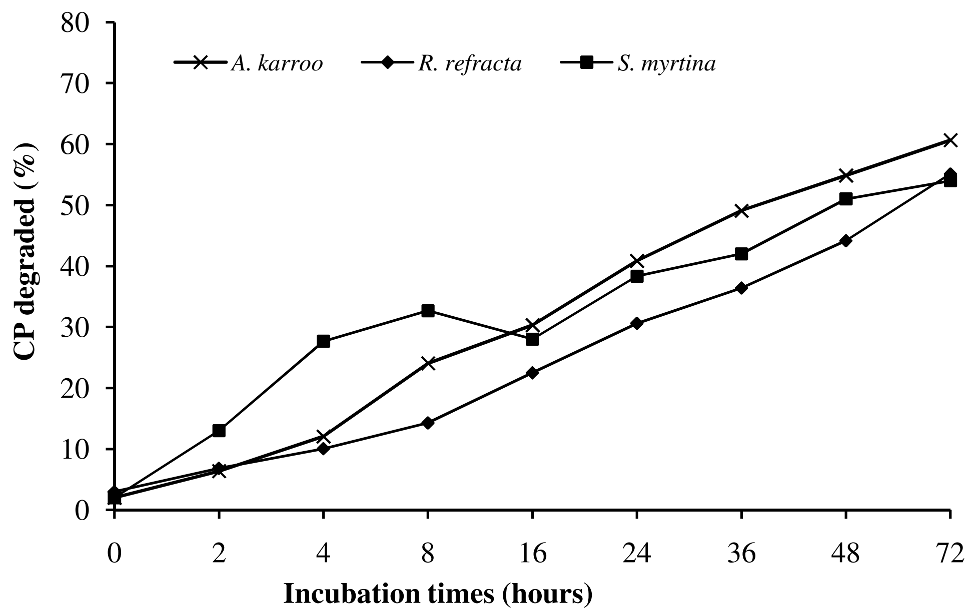

Figure 6.7. *In sacco* crude protein degradation of *A. karroo*, *R. refracta* and *S. myrtina* during the hot-wet season

A higher fraction of CP of both *R. refracta* (Tswana 39 %; Boer 22 %) and *S. myrtina* (Tswana 40 %; Boer 375) was degraded by Tswana goats than the Boer goats, after 24 hours of incubation (Table 6.7). Both breeds, however, showed similar degradation of the CP of *A. karroo* after 24 hours (41 %) of incubation. After 48 hours of incubation, the crude protein of *A. karroo* showed a higher degradability by Tswana goats (56 %) compared to Boer goats (54 %). Similarly the CP degradation of *R. refracta* (Tswana 55; Boer 33 %) and *S. myrtina* (Tswana 52; Boer 30 %), was greater in the Tswana goats than the Boer goats after 48 hours of rumen incubation.

The ruminal degradation constant (*a*) for *A. karroo* differed significantly (P<0.0001) between the Tswana (3.4 %) and the Boer (1.4 %) goats. Similarly, for *S. myrtina* the ruminal degradation constant (*a*) differed significantly (P<0.001) between breeds (Tswana 10.0 %; Boer 4.2 %). Boer goats, however, had a significantly higher ruminal degradation constant (a) for *R. refracta* compared to Tswana goats (Tswana 2.3 %; Boer 6.4 %). The fraction of crude protein of *R. refracta* percentage slowly degraded (*b*) was significantly higher (P<0.0001) for Tswana (81.1 %) compared to Boer (53.3 %) goats. Tswana goats also had a higher (P<0.0001) slowly degradable CP fraction (*b*) for *A. karroo* (Tswana 61.1 %; Boer 59.15%) and *S. myrtina* (Tswana 52.3 %; Boer 46.7 %). The rate of degradation (c h^{-1}) of the crude protein fraction of the three woody plant species by Tswana and Boer goats did not differ significantly (P>0.05).

Table 6.7. Estimated crude protein degradability parameters of *Acacia karroo, Rhus refracta* and *Scutia myrtina* during hot-wet season

Item	**(%) CRUDE PROTEIN DISAPPEARANCE**					
	Grewia occidentalis		***Olea africana***		***Scutia myrtina***	
Time (h)of Incubation	Tswana	Boer	Tswana	Boer	Tswana	Boer
0	2	2	3	3	2	2
2	9	4	7	7	16	10
4	13	11	9	11	24	13
8	24	24	13	16	24	23
16	31	30	25	20	26	30
24	41	41	39	22	40	37
36	50	48	47	26	44	40
48	56	54	55	33	52	50
72	62	59	67	43	58	50
DEGRADATION RATE CONSTANTS (± SE)						
a	$3.8^{d} \pm 0.024$	$1.4^{f} \pm 0.024$	$2.3^{e} \pm 0.024$	$6.4^{b} \pm 0.024$	$10.0^{a} \pm 0.024$	$4.2^{c} \pm 0.024$
b	$61.1^{b} \pm 0.024$	$59.2^{c} \pm 0.024$	$81.1^{a} \pm 0.024$	$53.3^{d} \pm 0.024$	$52.3^{e} \pm 0.024$	$46.7^{f} \pm 0.024$
a + *b*	$64.9^{b} \pm 0.005$	$60.7^{d} \pm 0.005$	$83.4^{a} \pm 0.005$	$59.7^{e} \pm 0.005$	$62.3^{c} \pm 0.005$	$50.9^{f} \pm 0.005$
c	$0.04^{a} \pm 0.005$	$0.05^{a} \pm 0.005$	$0.02^{b} \pm 0.005$	$0.02^{b} \pm 0.005$	$0.03^{b} \pm 0.005$	$0.05^{a} \pm 0.005$

a = Fraction of DM (%) lost during washing; *b* = Fraction of DM (%) degraded; *a* + *b* = Fraction of DM (%) potentially degraded; *c* = Rate of degradation of DM (h^{-1}); SE = Standard error, *n* = 3
Means in a row with different superscripts differ significantly (P < 0.05)

The percentage of crude protein of *R. refracta* potentially degraded (*a*+*b*) by Tswana goats was high (P<0.0001; 83.4 %) compared to that potentially degraded by Boer goats (59.7 %). Similarly for *A. karroo* and *S. myrtina*, the potentially degraded CP % (*a*+*b*) was higher for Tswana than Boer goats. The rate of degradation (*c*) of *A. karroo* and *R. refracta* did not differ significantly (P>0.05) between the breeds. However, the rate of degradation for *S. myrtina* was significantly higher (P<0.0001) for Boer than Tswana goats.

Dry matter and crude protein degradation of *A. karroo*, *R. refracta* and *S. myrtina* are graphically illustrated in Figures 6.8, 6.9 and 6.10.

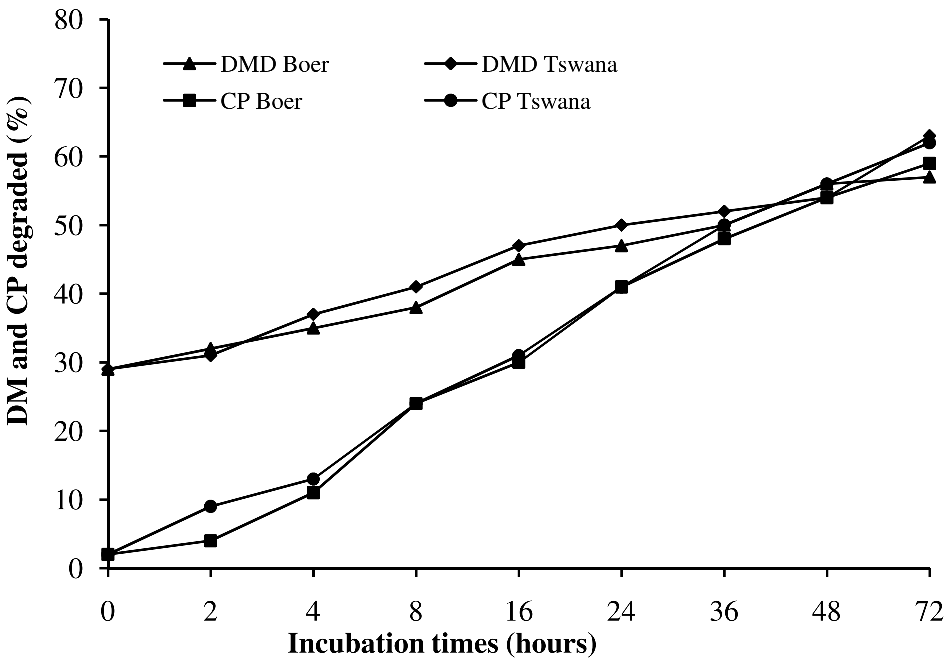

Figure 6.8. *In sacco* DM and CP degradation of *A. karroo* by Tswana and Boer goats during the hot-wet season.

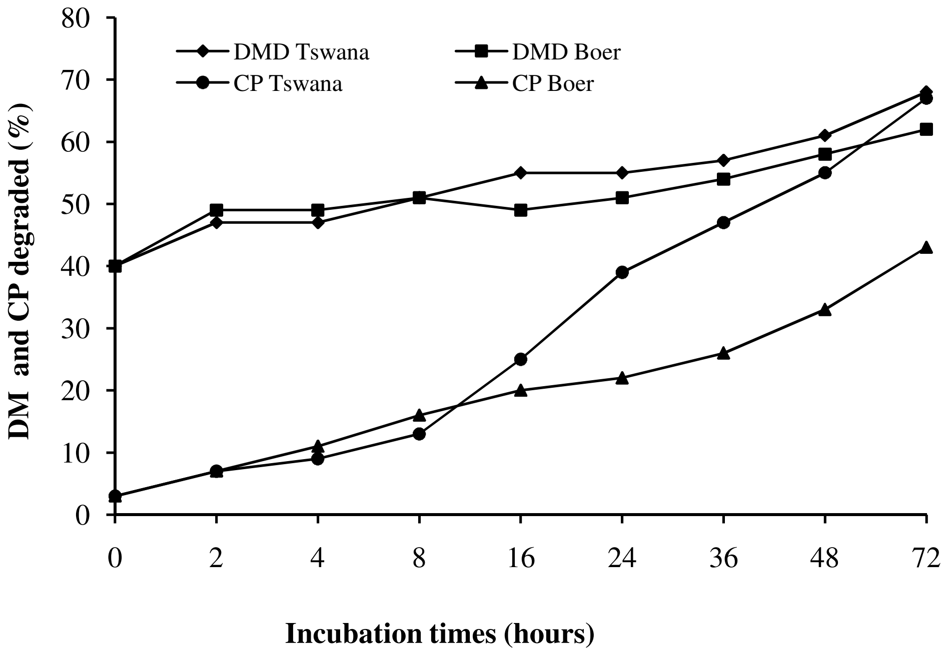

Figure 6.9. *In sacco* DM and CP degradation of *R. refracta* by Tswana and Boer goats during the hot-wet season

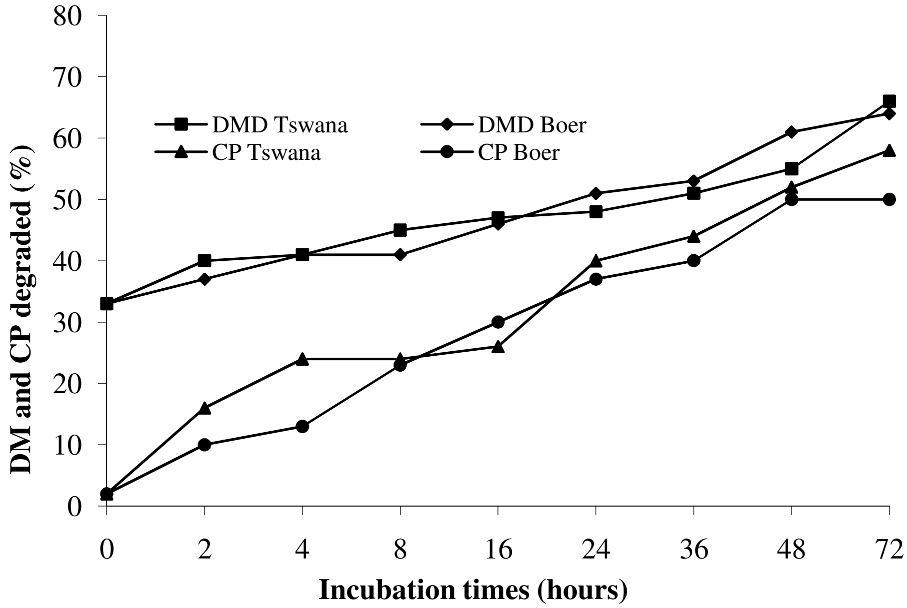

Figure 6.10. *In sacco* DM and CP degradation of *S. myrtina* by Tswana and Boer goats during the hot-wet season

6.4.7. Relationships between DMD, CPD and incubation time in Tswana and Boer goats during the hot-wet season

Dry matter and crude protein degradation for *S. myrtina* were highly correlated with the time of incubation in the rumen in both Tswana (r^2=0.96 P<0.0001 and r^2=0.93 P=0.0003 respectively) and Boer goats (r^2=0.96 P<0.0001; and r^2=0.91 P=0.001 respectively). There was also a strong positive correlation between DMD and CPD (Tswana r^2=0.96 P<0.0001; Boer r^2=0.98 P<0.0001). *Acacia karroo* showed strong positive correlation of both DMD (Tswana r^2=0.93 P=0.0002; Boer r^2=0.93 P=0.0003) and CPD (Tswana r^2=0.94 P=0.0002; Boer r^2=0.92 P=0.0004) with time of incubation in the rumen. Dry matter degradation was strongly correlated with CPD (Tswana r^2=0.98 P<0.0001; Boer r^2=0.99 P<0.0001). Similarly, for *R. refracta*, there was a strong positive correlation of both DMD (Tswana r^2=0.96 P<0.0001; Boer r^2=0.90 P=0.01) and CPD (Tswana r^2=0.97 P<0.0001; Boer r^2=0.97 P<0.0001) with the time of incubation in the rumen. There was also a strong positive correlation between DMD and CPD (Tswana r^2=0.98 P<0.0001; Boer r^2=0.94 P=0.0002). Equations for predicting DMD and CPD of woody plant species, in Tswana and Boer goats, during the hot-wet season are shown in Table 6.8.

Table 6.8. Equations predicting dry matter and protein degradability during the hot-wet season for Tswana goats and Boer goats

BREED	SPECIES	EQUATION	r^2
Tswana	*Scutia myrtina*	Y = 34.7 + 0.19 TIME + 0.28 CPD	0.96
	Acacia karroo	Y = 29.1 + 0.05 TIME + 0.45 CPD	0.96
	Rhus refracter	Y = 43.2 + 0.09 TIME + 0.34 CPD	0.96
Boer	*Scutia myrtina*	Y = 33.1 + 0.19 TIME + 0.35 CPD	0.99
	Acacia karroo	Y = 29.4 + 0.05 TIME + 0.42 CPD	0.98
	Rhus refracter	Y = 41.4 - 0.05 TIME + 0.56 CPD	0.88
Tswana	*Scutia myrtina*	Y = - 53.31 + 0.02 TIME + 1.77 DMD	0.93
	Acacia karroo	Y = - 42.55 + 0.15 TIME + 1.58 DMD	0.97
	Rhus refracter	Y = - 46.99 + 0.44 TIME + 1.19 DMD	0.97
Boer	*Scutia myrtina*	- 72.68 - 0.30 TIME + 2.28 DMD	0.96
	Acacia karroo	-58.32 + 0.02 TIME + 2.04 DMD	0.97
	Rhus refracter	-20.81 + 0.36 TIME + 0.63 DMD	0.97

6.5. Discussion

The ranges of NDF, ADF and ADL found in this study are comparable to earlier reports (Le Houerou, 1980, Onwuka *et al*., 1989; Rittner & Reed, 1992; Topps, 1992; Nsahlai *et al*., 1994; Larbi *et al*., 1997; Mogorosi, 2000; Rogosic *et al*, 2006). Seasonal variations in these constituents probably occurred as a result of differences in environmental conditions such as rainfall, temperature and relative humidity (Akkasaeng *et al*, 1989). The seasonal fluctuations in crude protein content may have been induced by the the hot-wet season (177 mm) precipitations, while low precipitations during the cold-dry season (84 mm) led to a decline in crude protein to levels regarded as being close to being deficient. The higher crude protein levels found in the diet during the hot-wet season are expected, because of the availability of new growth in woody components. Low protein content in the cold-dry season is expected when leaves mature (Owen-Smith, 1988), creating differences in leaf to stem ratio, and this is more pronounced in deciduous, rather than evergreen species. All the woody plant species with the exception of *O. africana* had crude protein levels greater than 7.5%. This is the lowest value for CP which is considered adequate to describe the forage quality, because it falls within the range of values for maintenance of goats (NRC, 1981).

The degraded dry matter and crude protein modeled with the Orskov & McDonald (1977) equation showed significant variability between the woody plant species. Ruminal degradation constants (*a, b* and *a+b*) also varied significantly (P<0.001) between breeds, as well as between goats within a breed. Because of the variation within a breed, no actual signficant breed differences were found in the *in sacco* degradation of DM and CP between Tswana and Boer goats.

The first loss from the bags (hour 0) was caused by the mechanical loss through the nylon bag wall, which means digestion by the animal per se started after hour 0. During the cold-dry season, the quickly degradable fraction (*a*) of DM was significantly higher (P<0.05) for *G. occidentalis* when compared to *O. africana and S. myrtina*. *S. myrtina* had the lowest (*a*) fraction of the three plants studied. However, the quickly degradable fraction (*a*) of CP was significantly higher (P<0.05) for *O. africana* when compared to *G. occidentalis* and *S. myrtina.* The fraction of DM percentage which was slowly degraded (*b*) was higher for *O. africana* and lowest for *S. myrtina.* The fraction of CP percentage slowly degraded (*b*) was significantly higher (P<0.05) for both *G. occidentalis* and *S. myrtina* compared to *O. africana.*

During the hot-wet season, the quickly degradable fraction (*a*) of DM was significantly higher (P<0.05) for *R. refracta* compared to *A. karroo* and *S. myrtina*. However, the quickly degradable fraction (*a*) of CP was significantly higher (P<0.05) for *S. myrtina* compared to *A. karroo* and *R. refracta.* The fraction of DM which was slowly degraded (*b*) was significantly higher (P<0.05) for *S. myrtina* compared to *A. karroo* and *R. refracta.* On the other hand, the fraction of CP percentage slowly degraded (*b*) was significantly higher (P<0.05) for *R. refracta* compared to *A. karroo* and *S. myrtina.* In summary, the DM of *G. occidentalis* would be digested the fastest in the cold-dry season, while in the hot-wet season *R refracta* would digest faster than the other preferred woody species. If the digestibility of CP is examined, *O. africana* and *S. myrtina* would be the fastest of the preferred species.

The degradation rate *in sacco* is a reflection of how fast the particular fraction of the plant will degrade in the rumen after being eaten and can be an indication of the relative importance of the plant in the diet. The potential dry matter degradability (*a*+*b*) is a measure of the proportion of the woody plant species that can be fermented in the rumen if the feed does not pass to the lower digestive tract before maximal degradation occurs (Mupangwa *et al*., 1997). The dry matter degradation rate of *O. africana* was significantly higher than of *G. occdentalis* and *S. myrtina* during the cold-dry season. Similarly, the potential degradability of DM (*a*+*b*) was significantly higher for *O. africana* and *G. occidentalis* when compared to *S. myrtina*. The rate of CP degradation was similar for all the three woody plant species. However, the potential degradability was higher for both G. *occidentalis* and *S. myrtina* compared to *O. africana*. During the hot-wet season, the DM degradation rate of *A. karroo* was significantly higher than that of of *R. refracta* and *S. myrtina*. However the potential degradability (*a*+*b*) of DM was lower for *A. karroo* when compared to *R. refracta* and *S. myrtina*. The rate of CP degradation (*c*) was similar for both *A. karroo* and *S. myrtina* but significantly different (P<0.0001) from *R. refracta*. Potential degradation was higher for *R. refracter* when compared to *A. karroo* and *S. myrtina*.

There was a strong positive correlation between DMD and the time of incubation in the rumen. Crude protein degradation also correlated positively with the time of incubation. The crude protein content of the woody plant species positively influenced the rumen digestion of dry matter because when CP increased DMD also increased.

6.6. Conclusions

The woody plant species showed great variation in chemical composition, dry matter degradation and crude protein degradation. All the browse species contributed substantial amounts of rumen degradable crude protein, dry matter and hence organic matter for microbial utilization, thereby increasing microbial protein synthesis and post ruminal supply of microbial protein. There was no breed difference in *in sacco* degradation of the woody plant species, as rumen degradation characteristics of DM and CP of browse species varied substantially between goats within a breed as well as between breeds from season to season. Rumen degradation characteristics could be used to characterise and detect variations in forage quality in browse species. The results from this research showed no breed difference in nutrient content and ruminal degradation of forages selected by the goats.

CHAPTER 7

CONCLUSIONS AND RECCOMENDATIONS

7.1. Feeding behaviour

The goats in this study did not follow the generally expected trend of being predominantly browsers. Grazing activity was high for both breeds, especially during the hot-wet season. The increased level of grazing is attributed to the high rainfall that was experienced in the hot-wet season. The high rainfall resulted in excessive growth of warm season grasses that were succulent, less coarse and highly digestible. This had a major impact on the dietary preference of goats, leading to high grass consumption.

The hypothesis that the Tswana goats spent more time browsing than the Boer goats was found to be true. Browsing was high for Tswana goats in the cold-dry season and low in the hot-wet season while Boer goats spent time browsing during both seasons which did not differ significantly between seasons. . The high browse consumption by Tswana goats during the cold-dry season can be attributed to the early and fast growth of grasses after the hot-wet season rainfall when legumes are still germinating, thus leaving the legumes fresh, less coarse and more succulent at the onset of the dry season. The breed differences in terms of browse consumption may indicate the adaptability of the Tswana goats to using browse in semi-arid environments.

The hypothesis that time spent browsing will be negatively influenced by the availability of forage turned out as predicted. The goats switched to grazing during the later days of occupation of a camp, when browse got depleted. The observed variation in feeding behaviour was probably a response to the relative availability of various grass and browse species during the period of study. As expected, non-feeding activities were higher during midday compared to morning and afternoon though there were no breed differences during both seasons. This was probably because the goats avoided grazing or browsing during the hotter part of the day.

Results from this study illustrate the complex dynamics of the feeding behaviour of the goats grazing on heterogeneous vegetation with diverse botanical composition**.** This study confirms the modification of feeding behaviour, in terms of grazing, browsing and non-feeding activities, as an efficient tool for goats to adapt to quantity and quality of their ingesta, in order to meet their requirements. The decrease in the most preferred feeds induced goats to diversify their diets. This indicates that the natural seasonal changes modify the feeding pattern of goats affecting proportions of grass or bush consumption according to their availability. A diurnal pattern of foraging observed in this study for both breeds indicates that goats were more selective in the morning than in the afternoon. This was one foraging strategy that goats utilised to select the most nutritious diets in the morning and limit rumen fill in the morning. This allowed for unselective feeding the afternoon to fill up the rumen for the evening. Significant differences that were found between the feeding behaviour of Tswana and Boer goats confirmed findings of several researchers that genotypic variation can also influence the feeding behaviour of goats.

7.2. Woody- plant species selection

The Tswana and Boer goats did not show major differences in diet selection patterns between browse species as expected. The eight most selected woody plant species were similar for both breeds only differing in order of preference. However, Tswana goats selected a higher proportion of woody plant species compared to Boer goats. Woody plant selection for Tswana goats was high in the hot-wet season, while Boer goats maintained the same frequency of selection during both seasons. The reason may be that indigenous Tswana goats are mostly found in semi-arid regions characterised by harsh environmental conditions. Browse plays a major role in the diet of these free ranging animals in these areas when grasses dry out during the cold-dry season.

Diurnal woody plant selection was more pronounced in Tswana goats while Boer goats showed no diurnal pattern in woody plant selection. The diurnal variation in woody plant selection occurred because Tswana goats needed to increase their nutrient intake as their grass consumption was lower than for Boer goats, while on the other hand Boer goats obtained most of their nutrients from the grasses. This demonstrates the importance of woody-plant species for indigenous goats in semi-arid and arid areas, and how these species contribute to the increase in availability of forage resources for free ranging animals.

The measured crude protein content was positively correlated to the ranking of woody palnt species by preference ($r = 1.00$, $P < 0.001$). This is because plants with high ranking based on preference, tend to have a high crude protein content and hence high intake and palatability.

Good grazing management of rangelands implies prior knowledge of the diet selection behaviour, since selection behaviour exerts a major influence on vegetation composition. Feeding practices that permit animals to choose between different plants create the opportunity to reduce costs and enhance performance on rangelands. How individuals learn to mix their diets from an array of diverse plants is likely to influence plant biodiversity because high amounts of nutrients in a plant will increase the probability that it will be grazed. Thus the traditional extensive grazing system is considered to be a useful tool for the conservation of plant biodiversity.

7.3. Nutritive value

Although there were notable difference in the seasonal concentrations of CP, NDF and ADF of diets selected by goats, however, against expectations Tswana and Boer goats selected forages not differing significantly in CP and NDF. The only significant differences were in ADF and ADL. Seasonal fluctuations in nutrient content of diets selected by goats may be attributed to the high rainfall experienced in the hot-wet season and the dry the cold-dry season. Another contributing factor may be the differences in the percentage of grass and browse selected by goats during both seasons. In the hot-wet season goats selected more grass that was fresh, succulent and high in nutrient content. During the cold-dry season, the low crude protein content of selected forages was expected as leaves of browse mature and dry out. Although Tswana goats included more browse in their diets compared to Boer goats, they too were unable to improve the protein content of the diet they selected. This was probably because grass consumption was much higher than browse consumption for both breeds. For goats to derive the maximum benefit of browse available in fodder banks, they should be able to select as much browse as possible, which was not the case in the present study. The low crude protein content was insufficient to meet the maintenance requirements of both breeds and indicates a need for protein supplementation if these two breeds of goats are to be successfully maintained in this area. This also implies that the camps used for the trials are not ideal for foraging goats during the cold-dry season.

Given the reputation of goats as opportunistic yet highly selective feeders, attention should be given to the occurrence and nutritional importance of the diet of free ranging goats in terms of both botanical composition and carrying capacity of the veld. Range management should capitalize upon opportunistic feeding. This means maintaining plant communities that are highly diverse in botanical structure. Species diversity plays an important role in diet selection, as plant species with different types of nutrients may affect forage intake and animal production. This knowledge will help livestock producers to capitalize on nutrient content to enhance intake, optimize forage utilization and ultimately improve performance of free ranging herbivores. Exposure to a variety of plant species may allow herbivores to select mixtures that results in more balanced diets.

7. 4. *In sacco* degradation

Across the breed, the nylon bag incubation revealed large differences in the rumen degradability of dry matter and crude protein of browse species in the cold-dry season and the hot-wet season. Ruminal degradation constants (a, b and $a + b$) varied substantially between breed and between goats within a breed. Therefore no significant breed differences could be identified, in terms of *in sacco* degradability of DM and CP, between the Tswana and the Boer goats. However, dry matter and crude protein degradation were highly correlated with time taken for the incubation. Rumen degradation characteristics could be used to characterise and detect variation in forage quality of the browse.

Results from this study will help to develop strategies to optimise range resources for sustainable animal production. The contribution of goats to the livelihood of farmers is immense. In order to target production improvement, the constraints limiting success should be identified. Tswana goats might be a more favourable breed in semi-arid savannah because of their smaller boy size and, therefore, absolute nutrient requirements as well as better reproductive performance when compared to Boer goats. However, when forage availability is not a limiting factor, Boer goats might yield better returns for the investment since they are superior in meat production.

FUTURE RESEARCH

The results from this research showed no significant breed differences in terms of nutrient content of the selected forages, nor in the ruminal degradation of browse species. Further research needs to be carried out in other areas of the country using the same breeds. This will clarify if any breed differences do exist when other browse species are utilized. Time slots used during the research to observe the feeding behaviour of goats were possibly too short, and it is suggested that a further study be carried out where there is continuous determination of feeding parameters. Included in these parameters should be direct observations on biting, the use of n-alkanes to determine intake and the effect of tannins in digestion. This will provide accurate information on the succession of species consumed and analysis of such data should improve the understanding of diet selection by grazing animals in a heterogenous environment. The study should also be extended further to include other goat breeds.