

THE DIGESTIBILITY AND DEGRADABILITY OF FEEDS AND PROTEIN SOURCES IN DOHNE MERINO SHEEP AND BOER GOATS

by

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

THE DIGESTIBILITY AND DEGRADABILITY OF FEEDS AND PROTEIN SOURCES IN DOHNE MERINO SHEEP AND BOER GOATS

The objective of this study was to evaluate Dohne Merino sheep and Boer goats in terms of the degradable parameters of a high-fibre diet, a low-fibre diet and two vegetable protein sources commonly used in South Africa. Differences between species were evaluated following the potential differences within species. The feedstuffs used were those for the following diets: low-fibre diet (LF); high-fibre diet (HF); sunflower meal (SFM) oilcake; and soybean meal (SBM) oilcake.

In the first trial, the digestible characteristics of the HF and LF diets were determined by means of a digestibility study. A 6 × 6 Latin square design was used to determine whether Dohne Merino sheep or Boer goat wethers differ regarding the digestibility characteristics of low- and high-fibre diets. The diets were fed once daily at 1.24 kg to all the wethers, which had *ad libitum* access to fresh water. Each period consisted of 10 days of adaptation and seven days of faecal and urinary sampling. The results indicated that the intake and digestibility characteristics of nutrients did not differ between sheep and goats. However, the different diets differed in terms of the nutrient intake and digestibility range of sheep and goats.

The second trial was an *in sacco* degradability trial to determine the dry matter (DM) and crude protein (CP) degradability of the LF, HF, SBM and SFM diets. Six Dohne Merino and six Boer goat wethers were fitted with rumen cannulae so that they could be used in the trial. All wethers received the same basal diet. The samples were incubated in the rumen in polyester Dacron bags, with the bags being removed at intervals of 0h, 3h, 9h, 12h, 24h, 48h, 72h, and 96h for the LF and HF diets. All the oilcake was removed at intervals of 0h, 2h, 4h, 8h, 12h, 16h, 24h, 36h and 48h. The sheep and goats were found not to differ from one another in terms of effective degradability of any of the feedstuffs concerned. However, within species differences were observed.

To establish a fully integrated outcome of degradability, the study described in the current thesis was structured in such a way that the *in vitro* trial ran parallel with the *in sacco* trial, being performed with the aid of a Daisy Incubator (ANKOM Technology Corp., Fairport, NY). Such a procedure was only adopted in relation to the SFM and SBM diets in order to evaluate their *in vitro* data in relation to the *in sacco* data. The same oilcake was tested in the case of both trials, with the composite sample of rumen liquid of four sheep or goats, which was used in the *in sacco* trial, also being used in the *in vitro* study. In the study, DM disappearance values were determined and fitted to a single-compartment model by means of an iterative least-square procedure in order to determine the DM and CP degradability parameters. The DM used *in vitro* or *in sacco* was compared, using the actual values obtained after 8h incubation, due to only a limited amount of residue being left after incubation. In the

study, the *in vitro* method overestimated the digestibility of SBM by 37% to 39% and the digestibility of SFM by 17% to 20% compared with that found to occur in the *in sacco* method. *In vitro* DM disappearance values for all SBM samples were found to be higher than those that were detected in the SFM samples. The percentage of *in vitro* true digestibility parameters was also calculated. No significant differences were found between species for effective degradability, though differences were observed within species between the two substrates concerned.

In conclusion, the sheep and goats used in the study were not found to differ in terms of digestion parameters when they were compared on different types of roughage or protein sources. However, within species differences were, indeed, found to occur. Sheep and goats digested the SBM better than they did the SFM.

SAMEVATTING

DIE VERTEERBAARHEID EN DEGRADEERBAARHEID VAN VOERE EN PROTEÏEN BRONNE IN DOHNE MERINO'S EN BOERBOKKE

Die doel van hierdie studie was om te bepaal of Dohne Merino skape verskil van Boerbokke in terme van degradeerbaarheidsparameters van 'n hoë vesel-, 'n lae veseldieët en twee plantaardige proteïenbronne wat algemeen in Suid-Afrika gebruik word. Die verskille tussen spesies is ge-evalueer en daarna die potensiele verskille binne spesies. Die volgende grondstowwe is geëvalueer: 'n laevesel-dieët (LF), 'n hoëvesel-dieët (HF), sonneblom-oliekoekmeel (SFM) en sojaboon-oliekoekmeel (SBM).

In die eerste proef is die degradeerbaarheidsparameters van die HF dieët en die LF dieët met behulp van 'n verteerbaarheidsstudie bepaal. Dohne Merino hamels of Boerbok kapaters was gebruik om te bepaal of skape en bokke verskil in terme van inname en degradeerbaarheid van voedingstowwe wanneer hul hoë- en lae vesel voere gevoer word. Al die hamels en kapaters het *ad libitum* toegang tot vars water gehad en hul was een keer per dag (1.24 kg) gevoer. Elke periode het bestaan uit 'n 10 dag aanpassingsperiode en 'n toegelate 7 dae vir mis- en urienmonster versameling. Die resultate het aangedui dat die inname- en degradeerbaarheidsparameters van nutriënte beïnvloed word deur verskillende diëte binne spesies. Geen verskille is gevind tussen spesies wanneer daar hoë- en lae kwaliteit voere gevoer is nie.

Die tweede proef was 'n *in sacco*-degradeerbaarheidsstudie om te bepaal wat die droë materiaal (DM) en ruproteïen (RP) verteerbaarheidsparameters van die HF dieët, die LF dieët, die SBM en die SFM is. Ses Dohne Merino's en ses Boer bokke met rumen kanullas is in die studie gebruik en al die diere het dieselfde basale dieët ontvang. Die monsters is in die rumen geïnkubeer in poliester dakronsakkies en die sakkies is verwyder na onderskeidelik 0 uur, 3 uur, 9 uur, 12 uur, 24 uur, 48 uur, 72 uur en 96 uur intervalle. Laasgenoemde intervalle was geldig vir die lae vesel- en hoëveseldieët. Die oliekoek se intervalle het verskil en is verwyder na 0 uur, 2 uur, 4 uur, 8 uur, 12 uur, 16 uur, 24 uur, 36 uur en 48 uur. Daar was geen verskille tussen spesies in effektiewe degradeerbaarheid nie, alhoewel verskille voorgekom het binne spesies. Skape verteer veselagtige grondstowwe meer effektief terwyl bokke weer hoë proteïen bevattende grondstowwe beter verteer.

Om 'n volkome geïntegreerde uitkoms van degradeerbaarheid te bewerkstellig is die *in vitro* proef en die *in sacco* proef gelyktydig gedoen. Die *in vitro*-degradeerbaarheidsstudie is met behulp van 'n ANKOM Daisy Inkubeerder uitgevoer (ANKOM Tegnologie Korp., Fairport, NY) vir net die oliekoek behandelings. Gedurende die studie is dieselfde oliekoek gebruik. 'n Saamgestelde monster van die rumenvloestof van vier van die skape of bokke wat vir die *in sacco*-studie gebruik was, is gebruik vir die *in vitro*-inkubasie van die monsters. DM verdwyningparameters is bereken en dan met 'n interaktiewe kleinste kwadraat prosedure op 'n een-kompartement model gepas om die *in sacco* DM-degradeerbaarheidsparameters te bepaal. Die DM verdwyning, na 8h inkubasie, was gebruik om die

in vitro en die *in sacco* metodes met mekaar te vergelyk, weens 'n beperkte residu na die afloop van die elke inkubasiestudie. Tydens die studie het die *in vitro* metode degradering oorskat in vergelyking met die *in sacco* metode. DM verdwyningswaardes vir al die SBM monsters was hoër *in vitro* as die SFM monsters. In die studie is die persentasie *in vitro* ware degradeerbaarheidswaardes bereken. Geen verskille is opgemerk tussen spesies vir effektiewe degradeerbaarheid nie. Daar was wel verskille binne spesies.

Om af te sluit het dit voorgekom dat skape en bokke nie verskil aan degradeerbaarheidswaardes wanneer daar 'n vergelyking was tussen verskillende vesels- en proteïenbronne nie, alhoewel verskille voorgekom het binne spesies. Skape en bokke het SBM effektief beter verteer as SFM.

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DEDICATION

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LIST OF ABBREVIATIONS

AA	amino acid
ADF	acid detergent fibre
ADIN	acid detergent insoluble nitrogen
ANOVA	analysis of variance
AOAC	Association of Official Analytical Chemists
BSE	bovine spongiform encephalopathy
CF	crude fibre
CP	crude protein
CSM	cottonseed meal
DE	digestible energy
D _{eff}	effective degradability
DM	dry matter
DOMR	digestible organic matter fermented in the rumen
DP	digestible protein
EU	European Union
HE	high-energy
HF	high-fibre
IVTD	<i>in vitro</i> true digestibility
LF	low-fibre
MBM	meat and bone meal
ME	metabolisable energy
N	nitrogen
NDF	neutral detergent fibre
NFC	non-fibre carbohydrate
NFE	nitrogen-free extract
NPN	non-protein nitrogen
OM	organic matter
RDP	rumen-degradable protein
RFC	readily fermentable carbohydrate
RUP	rumen-undegradable protein
SBM	soybean meal
s.d.	standard deviation
s.e.	standard error
SFM	sunflower meal
TDN	total digestible nitrogen
UDP	undegraded dietary protein
VFA	volatile fatty acid
VFI	voluntary feed intake

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NOTES

The language and style used in this thesis are in accordance with the requirements of the Department of Animal Science, Stellenbosch University. This thesis represents a compilation of manuscripts, with each chapter serving as an individual entity, resulting in some unavoidable repetition of certain portions of the chapters concerned.

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CHAPTER 1

Introduction and Literature Review

1. General Introduction

The domestic goat (*Capra aegagrus hircus*) is significant throughout the world today, fulfilling a number of needs of various cultural groups. The three most important uses of goats comprise the use of their meat, fibre and milk. Important characteristics of goats are their hardiness and adaptability, as they are able to survive under the most extreme conditions. Goats are found all over the world, no matter whether the terrain is flat or mountainous and no matter whether the climate is hot, cold, wet or dry. Not only do such animals survive under relatively harsh conditions, but they also generate products in the form of meat, fibre and milk. In addition to their importance in such major areas of the economy, goats are also starting to find increasing application in niche areas. Such niche areas include bush control in traditional grassland environments (seeing that goat's milk contains 4.3% lactose, and cow's milk 5% lactose, such milk is not fit for inclusion in lactose intolerant diets), as well as in certain food products, such as course cheeses for food connoisseurs. Worldwide, the dairy goat population has increased by 52%, while in the developing and developed countries there has been an increase of 56% and 17%, respectively (Thornton, 2001).

In African society, sheep and goats comprise a large proportion of the total wealth of poor families, being their primary source of meat and milk products. Such flocks, which are raised in a wide variety of ecological zones, are able to survive and produce such products under harsh environmental conditions, which might not be suited to cattle grazing. In both desert and tropical environments, feed resources are restricted in terms of both quantity and quality. Therefore, differences among ruminants in terms of their energy requirements and digestive efficiencies are very important criteria for selecting the most appropriate type of animal to be kept in any particular circumstance (Sheridan *et al.*, 2003).

Goats differ from sheep in their feeding habits. The special feeding habits of goats are particularly significant in areas where the quantity and quality of feeds are low. Goats can subsist on feeds that would generally be considered to provide substandard levels of nutrition for other ruminants. Nonetheless, there is currently no evidence as to whether goats have a superior digestive efficiency in comparison with that of other ruminants, and none also as to whether such a factor accounts for their successful adaptation to poor environments (Gihad, 1976).

Growth rates of Boer goats are generally lower than are those of sheep. However, under favourable nutritional conditions, weight gains of more than 200 g per day can be obtained in goats, compared with the maximum gain of 176 g per day under widespread subtropical conditions. The poorer growth rate of goats compared with that of sheep might be due to the fact that the former differ in their nutritional requirements from those of the latter, despite the former being traditionally reared on diets that have been formulated for the latter. Goats also have a lower intake of concentrated feed in

comparison with that of sheep, which might lead to their poorer performance in the feedlot (Sheridan *et al.*, 2003).

Goats and sheep may both be maintained on low residue rations, with sheep consuming as much ration as do goats (Aregheore, 1996). It has, however, also been reported that goats perform better on low-grade roughages (Sheridan *et al.*, 2003), and that goats digest more fibrous feedstuff than do sheep, resulting in superior nutrient digestibility by the former (Aregheore, 1996). In contrast, Jones *et al.* (1972) found that goats and sheep exhibited similar patterns in their ability to digest various nutrients in forage. The digestibility coefficients of goats and sheep have also been found to be similar; the only difference between the two species regarding such coefficients has been found to be the digestibility of protein, which appears to be greater in goats. Such comparatively high digestibility might result from the rumen of goats adapting rapidly to new dietary conditions to produce microbial protein, which was a finding made by Sheridan *et al.* (2003). The aforementioned researchers also indicated that sheep and goats have a similar digestive efficiency on a diet of quality feed.

Supplementing wheat straw fed to sheep with rumen-degradable protein (RDP) helps to relieve the nitrogen (N) deficiency of such low-quality forages, as well as to enhance rumen fermentation and microbial protein synthesis, thereby addressing intake and digestibility limitations. Unfortunately, the high cost of protein supplements still limits the extent of such enrichment of low-quality forages with amino acid (AA) nitrogen sources. Such a shortcoming provides opportunities for further research into the potential of substituting AA nitrogen with non-protein nitrogen (NPN) in RDP supplements for sheep grazing on low-quality forage (Nolte *et al.*, 2003). Despite the previously mentioned reports on the similarity of goats to other ruminants in terms of general digestive efficiency, there is considerable evidence that goats are exceptionally efficient in digesting crude fibre (CF) (Gihad, 1976). Aregheore (1996) suggests that the grinding of residue before incorporating it with other ingredients prevents the selective consumption of rations.

Supplementation in most areas where domestic ruminants graze is an important factor to consider when making decisions regarding feed management. The providing of nutrients to offset deficiencies or to meet production demands is generally practised during periods of summer dormancy or during autumn and winter. Supplementation can take the form of substitution in the case of grazed nutrients being removed from animal diets in exchange for supplements. Both supplementation and substitution may be advisable at specific times, depending on such factors as forage quantity and quality, and production demands. Where the amount of energy which is available from grazed forage is too low to meet production demand, some form of energy supplementation is often practised. Optimising the energy supplementation of ruminants requires understanding of the dietary needs of animals (Caton & Dhuyvetter, 1997).

High-concentrate diets are routinely fed to cattle and sheep in order that they might capitalise on more rapid and less expensive gains than those that can be accomplished with forage alone. Feeding high-concentrate diets to young animals has typically resulted in the securing of relatively high-quality carcasses. In addition, the feeding of high levels of concentrates to sheep has been shown to shorten

the amount of time which is required pre-slaughter, while increasing the dressing percentages and the carcass quality (Ryan *et al.*, 2006). Ryan *et al.* (2006) found that Boer goats could be finished on a diet with a lower metabolisable energy (ME) value than that which is usually formulated for sheep, without a reduction in performance. Such findings indicate that a direct economic advantage might be gained by finishing Boer goats in the feedlot. In addition, the aforementioned authors also found that high-energy (HE) diets tended to increase carcass weight.

2. Low- and High-Quality Diets

Breeds or biological types with a high growth potential generally have greater maintenance energy requirements than do those with a lower growth potential. In general, the high production potential of some biological types can only be found with non-stressful nutritional environments or high-quality diets. High-quality diets elicit high peripheral tissue energy accretion, which allows a level of feed intake which more than compensates for the high-maintenance energy demand of fasting heat production. Thus, the intake of very low-quality, forage-based diets relative to body weight tends to be greater for biological types with low production potential than it would be for those with high production potential. Feed intake and energy accretion increase in line with improved forage quality for animals with high potential (Goetsch, 1998).

In relation to forage which is commonly fed to livestock, the term 'fibre' refers to the plant cell wall. Mammals do not possess a sufficient quantity of enzymes to hydrolyse the predominant β -1.4 linked polysaccharides which occur in cell walls, instead, they have to depend on a greater presence of micro-organisms in their gastrointestinal tract to ferment such polysaccharides into absorbable nutrients. Ruminants are among the most specialised herbivores that utilise such a symbiotic relationship to exploit plant cell walls as a source of nutrients (Jung, 1997a).

Ruminant animals have the ability to convert relatively low-quality feed into feed which provides relatively high-quality protein. Such conversion is made possible by the ruminal micro-organisms, which synthesise and secrete the β -1.4 cellulase enzyme complex, thereby allowing the hydrolysis of plant cell walls. However, the actual conversion of feed, especially that which consists of fibrous forage, to animal product is relatively inefficient. Only 1% to 35% of energy intake is captured as net energy, with 20% to 70% of the cellulose not being digested by the animal (Gabriella & Kolver, 1997).

Shirley (1986) compared the apparent digestibility and metabolic utilisation by goats and sheep of rich forage (berseem, an Egyptian clover – *Trifolium alexandrinum*) with that of two poor forages (high CF and low protein content). In goats which were fed the poor forages, the presence of rumen volatile fatty acid (VFA) and gas were relatively high, with ammonia production being relatively low and nitrogen retention being relatively high in relation to that of sheep. In the case of a diet of berseem, such differences between the goats and sheep were either absent or minimal. Shirley's study seems to indicate that goats tend to use those carbohydrates which are contained in the cell wall, as well as the ruminal ammonia of poor-quality forage, more efficiently than do sheep. Similarly, the goats' synthesis of microbial proteins was found to be superior on such a diet to that of sheep. Such characteristics of the goat might be much more difficult to observe with good- or medium-quality

forages. With good- and medium-quality forages grown in intensive or semi-intensive conditions, the apparent digestibility coefficients of dry matter (DM), organic matter and crude protein (CP) have been reported to be very similar for both goats and sheep, though the results regarding cellulose digestibility have been found to be inconsistent. The organic content of poor-quality forages, particularly of tropical forages, has not yet been found to be better digested by goats than by sheep. In some cases, protein has been reported to be digested slightly better, with, in most cases, CF having been reported to be better digested by goats than by sheep (Gall, 1981).

Sheep consume as much fibrous ration as do goats, and even higher than the latter do if the residues are processed, thus negating the selectiveness of sheep for more palatable food (Reid *et al.*, 1990; Aregheore, 1996). The ability of sheep to respond better than do goats to a relatively high-quality environment makes them more efficient utilisers of a high-quality diet (Sheridan *et al.*, 2003). Comparative research into the energy utilisation of sheep and goats consuming moderate- to low-quality diets has also revealed that, despite their similar energy utilisation, goats have often been found to utilise nitrogenous compounds in such diets more efficiently (Kronberg & Malechek, 1997). Despite the presence of tannins in forage having been found to have what appears to be a negative effect on nitrogen metabolism, Alcaide *et al.* (1997) concluded that goats tend to have the capacity to adapt to obtaining nutritional benefits from such tannins. Why sheep tend to benefit more from an HE diet than do goats might be due to the fact that, given the historical importance of wool, the former tended to be allocated better pasturage than were goats. Despite both species being concentrate selectors, sheep have tended to have access to grain, while goats have tended to be restricted to ligneous-rich areas, allowing for such adaptation to select foliage. Sheep may, therefore, have developed a greater capacity to digest starch than that which has been developed by goats, in general (Sheridan *et al.*, 2003). Gihad and El-Bedawy (1980) state that goats, being the most rugged grazers among all domestic livestock, prefer to consume browse plants, which form approximately 60% of their diet, with grasses and selected forbs, when such are available, forming the remaining 40%. Sheep, in contrast, tend to consume approximately 10% of their diet in the form of browse plants.

Feed resources containing less than 7% CP generally do not support optimum rumen fermentation. The concentration of neutral detergent fibre (NDF) in forage-based diets is considered to be the main dietary factor limiting their intake. Intake and digestibility are not optimum when forages contain low CP and high fibre (HF). Animals consuming poor-quality forages often fail to obtain sufficient nutrients from their diet to meet maintenance requirements (Mekasha *et al.*, 2002).

Merchen *et al.* (1986) found that diets containing 25% forage resulted in shifts in ruminal fermentation patterns and increases in the efficiency of bacterial protein synthesis, which did not occur with increased intake of diets containing 75% forage. Digestive interactions have been shown to occur in the absence of additives in the digestible fraction of feeds to the diet (Sanon *et al.*, 2007).

The low digestibility of hay can be related to its low CP content, with the apparent digestibility being shown to approach the value 0 when CP content declined to around 3%, which had the potential of leading to a negative nitrogen balance. Sanon *et al.* (2007) found negative digestibility of CP in sheep with *Cenchrus ciliaris* hay containing 4.6% CP. In contrast, Goromela *et al.* (1997, as cited by Sanon

et al., 2007) did not find negative digestibility in goats consuming hay containing less CP (2.7%). More NDF was digested from the hay by the goats than was digested from the browse forage. Such a result might be due to the presence of lignin and/or anti-nutritional factors, which, in association with the presence of cell walls, tends to limit microbial degradation, as well as to inhibit the activity of rumen microbes. The fact that lignin is a component of the cell wall directly influences the digestibility of such material, and hence also the digestibility of the forage concerned. Jones *et al.* (1972) showed that the digestible energy (DE) of silage fed to sheep was largely influenced by its nutrient content, most notably in relation to the percentage of CP and the digestibility of DM. Approximately 86% and 87% of the variation in rumen acetate and propionate, respectively, was attributed to the intake of feed, to the digestible nutrients and CP, as well as to the cellulose content, of the silages concerned. Although non-significant, the slight differences in nutrient digestibility and DM intake by sheep that were detected in the study concerned might have been sufficient to result in the differences in rumen VFA patterns between the species concerned. The nutritive value of a feed is a function not only of chemical composition, but also of its intake characteristics, as well as of the efficiency of extraction of nutrients from the feed during digestion (Sanon *et al.*, 2007). Ammerman *et al.* (1972) found that nitrogen intake was a major factor influencing the intake and digestibility of low roughages by ruminants.

Goetsch (1998) noted differences in fasting production between sheep which were unselected for rate and efficiency of growth, observing similar partial efficiencies of ME use for maintenance and tissue accretion. DM intakes were found to differ significantly between goats and sheep when wilted lucerne silage and high DM corn silage were fed to them. In both cases, the sheep were found to consume more forage DM than did the goats (Jones *et al.*, 1972). Gihad (1976) showed that, in comparison with the sheep that they studied, goats tended to consume more DM from tropical hay (Aregheore, 1996), indicating the superior capacity of the latter to utilise feed efficiently. Although goats and sheep have been found to exhibit similar patterns in their ability to digest the various nutrients which are present in hay, the former have been found to exhibit a greater capacity to digest CF than do sheep. In sheep, the low digestibility coefficients of CF might partially be attributed to high water consumption, which might have promoted faster rumen washout, with a resultant faster passage than that of goats (Ammerman *et al.*, 1972).

Four major factors regulate ruminant fibre digestion (Gabriella & Kolver, 1997):

- plant structure and composition, which regulate bacterial access to nutrients;
- the nature of the population densities of the predominant fibre-digesting micro-organisms;
- the microbial factors, which control adhesion and hydrolysis by complexes of hydrolytic enzymes of the adherent microbial populations; and
- animal factors, which increase the number of nutrients which are made available by means of mastication, salivation and digesta kinetics.

Goats are reported to differ from sheep in terms of their diet selection and gastrointestinal physiology (Huston, 1978). Several researchers have observed slower growth rates and greater fat deposition in those goats which are fed HE diets compared with those which are fed pasture-based diets. Although those lambs which have been fed an HE diet were found to consume less than did lambs fed a low- or medium-energy diet, the former were found to be more efficient converters of feed (McGregor & Umar, 2000; Sheridan *et al.*, 2003). Increasing the amount of energy intake, while keeping the protein intake constant, has been shown to increase fat deposition in sheep (Broster, 1973). When measuring the degree of rumen metabolism for both goats and sheep, the molar percentage of acetate was determined to be slightly higher in goats than it was in sheep, while propionate and butyrate levels were found to be greater in sheep (Jones *et al.*, 1972). The degree of lignin digestibility in lucerne silage was found to be high in both goats and sheep.

Aregheore (1996) found that sheep had higher daily live weight gains than did goats. Although Jones *et al.* (1972) suggest that goats and sheep were similar in their digestive capacity for all nutrients when three different forages were evaluated, higher levels of digestibility were observed in goats when they were fed second-cut lucerne hay. Goats have been reported to pass larger particles through their alimentary tracts than do sheep. The capacity of goats being proportionately greater than that of sheep, might have accounted for the difference which was obtained in the related results (Aregheore, 1996). The ability of goats and sheep to maintain their body weight throughout the growth phase, as well as thereafter on a crop residue ration, is of considerable economic importance.

3. Associative Effects between Forages and Grains

In ruminant animal production systems, it is often appropriate to provide both grain and forage in the diet, despite the former usually being more costly per unit of energy or protein. The associative effects between the forage and grain components of such diets, in some circumstances, has important consequences for the efficiency of utilisation of the nutrients in the grain and forage concerned, as well as for product quality. The ruminant digestive system creates both opportunities and difficulties for the maximisation of the efficiency of feed utilisation.

An adequate supply of nutrients might improve the nutritive value of low-quality diets (Salem *et al.*, 2004). The voluntary intake of low-quality diets by ruminants can be increased by adding soybean meal (SBM) to such diets (Church & Santos, 1981). Stokes *et al.* (1988) showed large increases in DM intake when SBM was given, compared with small elevations which were obtained in ruminal digestion, implying that metabolic regulation modified the intake of low-quality forages.

- Compared with sheep, goats have been shown to have a higher digestive capacity when consuming roughages containing low amounts of nitrogen and high amounts of lignin. Alcaide *et al.* (1997) ascribed such differences to: (a) the ability of goats to select the parts of plants with the highest nutritive value; (b) the greater retention time of the digesta in the rumen of goats; and (c) the interspecies differences to be found in the rumen environment, such as a

higher production of microbial protein, or a higher number of cellulolytic bacteria, in goats than in sheep.

In many areas of the world, low-quality roughage is the only feed available to grazing animals for a considerable portion of the year. Low-quality roughages are usually unpalatable, fibrous and often deficient in nitrogen, phosphorus, vitamin A and trace minerals. Supplementary protein has been shown to improve the utilisation of low-quality roughage in many trials (Church & Santos, 1981).

Although microbial fermentation in the rumen allows the digestion of fibrous plant material, the fermentation of such feeds as grains, prior to their exposure to digestion in the small intestine, might result in inefficiencies. Since most storage carbohydrates in grains are readily fermented by the rumen micro-organisms, most of the DE in grains becomes available to the ruminant in the form of VFA's and microbial biomass, rather than as monosaccharides, as is the case with monogastric animals. Rumen fermentation, theoretically, reduces the energy value of grain starches by between 30% and 50%, although the post-ruminal digestion of the micro-organisms which are synthesised in the rumen increases the supply of absorbed AA's. The optimal balance which is achievable between the rumen and post-ruminal tract for the digestion of grains can be expected to vary with the nutritional needs of the animal concerned, as well as with the supply of nutrients which are available from the other diet components. In the case of a growing animal, using the rumen to digest plant fibre, as well as to produce microbial protein from low-quality substrates, is often advantageous, while doing so also helps to ensure satisfactory digestion throughout the gastrointestinal tract of the starch and protein content of grain.

The associate effects, which often occur when both grain and forage are included in the diet of ruminants, are due to digestive and metabolic interactions, which serve to modify the intake of DE, and therefore of ME. Positive associative effects occur when the ME intake from the combined forage and grain components is greater than that which is expected from either of the components when it is fed alone. Negative associative effects occur when the ME intake is less from the combined feeds than that which is expected from either of such feeds when it is used alone. Usually associative effects are due primarily to the inclusion of grain in the diet, which changes the degree of voluntary intake of such material. In addition, the efficiency of utilisation of absorbed nutrients for the synthesis of animal tissues or products tends to increase when grain is incorporated in a forage diet (Dixon & Stockdale, 1999).

Positive associative effects most often occur when a forage containing a low concentration of a limiting nutrient for either the rumen microbes (e.g. nitrogen or sulphur) or the animal concerned (e.g. phosphorus) when the diet of grain containing a high concentration of such a nutrient, with the latter supplying sufficient amounts of the nutrient to balance the entire diet. Though a limiting nutrient might be deficient in the grain, it might be supplied by the forage (e.g. in the use of low-protein or low-sulphur grains). However, such situations are relatively rare. Such positive associative effects can usually be identified by means of the application of routine diet formulation procedures (Broster, 1973; Dixon & Stockdale, 1999).

Negative associative effects often occur when grains constitute a substantial proportion of mixed forage–grain diets, and might cause large losses in efficiency. In many feeding systems, it is difficult to achieve satisfactorily high digestibility of grain in the rumen, resulting in adverse effects on rumen forage digestion. Generally, the amount and type of forage has little effect on the digestion of grains, with any positive or negative associative effects being due to changes in the microbial digestion and intake of the forage concerned. Negative associative effects often have major consequences on the efficiency with which grain supplements increase the ME intake of high-digestibility forages, as well as with forages of low to moderate digestibility. In one study, for example, when barley grain supplement, comprising 40% of total intake, was fed together with medium-digestible forage, the total ME intake was increased by only 15% of the ME ingested in the supplement (Dixon & Stockdale, 1999). When negative associative effects occur with low- to medium-digestibility forages, such effects are most commonly due to the readily fermentable carbohydrate (RFC) components of the grain reducing the rate of rumen microbial digestion of the fibrous components of forage, thus reducing the intake and digestion of forage throughout the gastrointestinal tract (Dixon & Stockdale, 1999). However, Maklad (2001) found that the inclusion of SBM in a low-quality diet improved digestion and fermentation in small ruminants.

Studies have also shown that further supplementation of roughage diets with maize grain reduced urinary nitrogen in some, though not all, cases when the diet which was provided for sheep was supplemented with forage legumes. Since maize ferments at a slower rate than do some forage legumes, the complementary effect of such fermentation might well vary with the degradability of the forage legume (Nsahlai *et al.*, 1998).

4. Concentrate Feeding

Goats may partly or completely refuse concentrates due to the physical form or defective conservation of such concentrates (Gall, 1981), although Ryan *et al.* (2006) found that goats fed concentrate diets tended to be fatter than were control animals which were not fed such diets. Providing coarsely ground or pelleted concentrates is preferable to providing finely ground ones, in that the former reduce the amount of waste and the risk of introducing fine particles into the lungs of the animals which are fed on such diets. Goats seem to be more susceptible to concentrate quality than are other ruminants, as they tend to reduce their intake substantially when the concentrate which they are fed is mouldy or fermented. If cereals are in an acceptable form, they are generally well accepted (though wheat is sometimes less well accepted), as are milling by-products (including cereal shorts, screenings and brans) and oilcake meals (such as those containing groundnuts, linseed, soybeans and sunflowers). The inclusion of rapeseed meal might decrease the acceptability of concentrates, although such an effect has not been found to be constant. The inclusion of dehydrated lucerne flour and some animal fats in some concentrates might lead to their poor acceptance. The amount of concentrate which is given to goats as a supplement to their basal diet is generally determined not only from a technical viewpoint, but also from an economic viewpoint, according to concentrate prices and the production of the animal concerned.

Although the same fundamental nutritional principles observed in relation to other ruminants also apply to goats, their particular feeding behaviour must be taken into account for effective feed management. Further research into intake levels, feed efficiency and nutrient requirements should help to establish herd feeding programmes suitable for intensive production conditions. Such data are currently unavailable, particularly with respect to the use of poor-quality forage and to the browsing of goats. Owing to the capacity of goats to adapt to diverse environmental conditions, goat production might be capable of expanding in diverse areas, in which goats have advantages over other ruminants. For instance, under extensively arid conditions, goats might be the only animals capable of thriving, due to their feeding behaviour. Alternatively, under intensive conditions, goats can produce efficiently, due to their high feed intake and production outcome (Gall, 1981).

Low-digestibility forages are often deficient in essential microbial substrates. The dietary inclusion of grain products which contain such substrates might have beneficial, neutral or adverse effects on rumen digestion of forage, depending on the relative importance of essential microbial substrates and RFC in fibre digestion. In general, when substitution does occur, such substitution is most likely due to dietary RFC reducing fibre digestion in the rumen, and thereby also reducing the amount of removal of the fibrous components of the forage, which constitute the principal component of rumen fill. Due to such effects as changes in rumen fill, it has been suggested that the relationship between the rate of rumen digestion of forage fibre and the intake of low-quality forages is likely to be complex (Dixon & Stockdale, 1999). However, Maklad (2001) found that the quality of fermentation is affected by the type of roughage being consumed. Microbial activities in the rumen differ according to the type of roughage, depending on the relationships between non-fibre carbohydrate (NFC) intake, degradable protein intake and the type of hemicelluloses present in the roughage.

A decrease in the intake and digestion of forage components might also occur when a supplement containing other forms of RFC (such as legumes or molasses) is fed to the animals concerned, indicating that such a decrease is likely to result from the ingestion of RFC. Although there are many reports of increased intake of low-quality forages after supplementation available, such positive associative effects can usually be regarded as resulting from the addition of a limiting nutrient, such as nitrogen or sulphur, to the supplement concerned. For example, a high protein concentrate has been shown to stimulate the intake of oat straw, though such increased intake was shown to be due to the addition of nitrogen to the straw, rather than to the RFC components which were contained in the supplement. Providing such microbial substrates as nitrogen or sulphur in inorganic forms is likely to be the most effective method of increasing ME uptake, with oilcake supplementation being the alternative option (Dixon & Stockdale, 1999).

5. Energy

Ensuring an adequate energy supply for an animal is a primary consideration in its feeding (Garrett *et al.*, 1959). The protein requirements of small ruminants depend on the level of energy supplied to them (Broster, 1973). The supply of nitrogen and energy are closely associated dietary factors in the nutrition of ruminants. Though ruminal microbes tend to utilise energy from lignocelluloses and other

cellulosic cell wall constituents, as well as from starch and simpler metabolites, in addition they tend to require nitrogen for cellular protein synthesis and multiplication. The associative effects of energy and protein, in conjunction, have long been known, having been reviewed in the literature as early as 1962, as has been reported by Thornton (2001). Such effects have proved to be complex, with the relationship between the two nutrients appearing to be very close.

6. Protein Sources

In general, the more processed that a supplement is, the more that the protein which it contains is protected from degradation in the rumen. Highly processed protein meals, such as those containing fish and blood, are excellent sources of undegradable dietary protein, whereas many other protein meals are only moderate sources of undegradable dietary protein. Maize, sorghum and rice are also moderate sources, whereas other cereal grains, such as wheat, triticale and barley, which are used as feed in temperate countries, tend to be poor sources of undegradable protein. Formulated concentrates can be moderate sources of protein when pelleted or poor sources are provided as meals. Forages conserved as hay tend to be moderate sources of protein, but only poor suppliers of undegradable dietary protein when the forages are fresh or ensiled (Moran, 2005).

If different raw materials (protein sources, in this case) are to be optimally utilised to manipulate the gut environment and to influence animal production, it is imperative that animal nutritionists thoroughly understand the chemical issues relating to the raw materials being used. The current section of this thesis is aimed at providing relevant information on the chemical aspects of protein sources, which might allow animal nutritionists to manipulate animal production through feed formulation.

Proteins, which can be categorised on the basis of their chemical entities and reactivity (Thornton, 2001), are commonly divided into:

- forages (consisting of dried or conserved forages); and
- processed protein sources (consisting of plant or animal sources).

Both of the above categories, despite their being constituted of similar protein fractions, differ in terms of the availability and/or degradability of each fraction concerned. Due to such a difference in protein fractions, animal feed specialists are able to manipulate animal nutrition and to improve production, no matter whether it is environmental or managerial, under different conditions (Thornton, 2001).

Goats are important livestock in respect of food and economic security, particularly in developing countries. However, relatively little research has been conducted into the requirements of goats in respect of nutrients, particularly protein, when compared with other livestock species. To best address the protein need of ruminants, it is now generally accepted that both the feed protein, which reaches the small intestine intact, and the microbial protein, which is synthesised in the rumen, should be considered, along with the necessary adjustments which are required to be made in relation to the extent of degradation which occurs in the small intestine (Lu *et al.*, 1990).

The measurement of microbial protein supply to ruminants has been an important area of study in ruminant protein nutrition. Estimates of microbial protein contribution to the intestinal protein flow have been incorporated into the new protein evaluation systems, which are already being used in various countries. The supply of microbial protein to the animal per unit of feed ingested, which is usually expressed as g microbial N/kg digestible organic matter fermented in the rumen (DOMR), has been found to vary by almost four folds (14–60 g N/kg). Such variation is reported to be due to the influence of various factors relating to the diet or rumen environment (Chen & Gomes, 1992). The effects of many such factors have not yet been either conclusively demonstrated or quantitatively defined. Addressing the possible differences in ruminant environments between goats and sheep when they consume high- or low-quality forages is, therefore, important. The influence on the inclusion of protein sources in the diet might also have a significant effect on the ruminant environment.

6.1 Forages

6.1.1 Fresh forages

Worldwide, forages, generally being consumed *ad libitum*, provide most energy in ruminant production systems. Inherent in most theories of physiological control of forage intake is the importance of the efficiency of energy metabolism, or the proportion of metabolised energy which is used in tissue maintenance and accretion, as well as in product secretion (Goetsch, 1998).

Feeds that contain 18% or more of CF on a DM basis are classified as forages or roughages. The level of ruminant nutrition which is related to the ratio of roughage to concentrate in diets has been extensively investigated. Replacing part of the concentrate in a diet by means of the addition of an equal weight of roughage will reduce its energy content. A small decrease in energy intake will decrease the amount of energy in weight gain, while producing little or no effect on the rate of gain, resulting in the improvement of feed efficiency. However, if the energy intake is restricted still further, daily gains will decrease to a point where the energy requirement for maintenance will nullify such an effect. Roughages, at some level, are generally essential for the maintenance of microbes in the rumen, as well as for the overall performance of ruminants. However, many types of roughage, when provided alone as feed, will provide only small gains or maintenance requirements, or, else, may be inadequate to maintain body weight. The nutritive value of roughage is generally inversely related to its fibre content. The degree to which ruminants adapt to high-fibre diets varies with the proportion of structural carbohydrates contained in the plant cell walls. Both the quality of fibre and its influence on the utilisation of non-fibre components of the diet are important factors in ruminant performance (Shirley, 1986).

Forages are not only a source of fibre and carbohydrates, but also of protein. Forages are presented to the animals in different forms, namely fresh, dried (in the form of hay) or conserved (in the form of silage). The form in which forages is presented largely depends on the farmer, as well as on the environment of the farm or the climatic zone in which the farm is situated. In terms of protein fractions, all forages may contain the following (Thornton, 2001):

- fraction 1 leaf protein,

- fraction 2 leaf protein,
- chloroplast membrane protein, and
- other fractions.

Fraction 1 leaf protein constitutes about 38% of the total leaf protein, mainly consisting of chloroplastic proteins. Such chloroplastic proteins are mainly in the form of an enzyme called ribulose-1.5 biphosphate carboxylase. Such an enzyme is common in C₃ plants, such as lucerne. In contrast, in C₄ plants (such as maize), the Fraction 1 leaf proteins are absent from the normal chloroplasts, though they are found in the bundle sheath chloroplasts. The Fraction 1 leaf proteins are highly soluble in water and degrade rapidly in the rumen (Thornton, 2001). According to Holter and Reid (1959), such solubility and rapid degradation shows that the digestibility of the protein increases exponentially as the concentration of CP in the forages increases.

The fraction 2 leaf proteins constitute about 25% of the leaf protein, being constituted of both chloroplasts and cytoplasm. Although the biological composition of such protein is known, and despite its being water soluble, little is known about its potential degradability in the rumen (Thornton, 2001).

The chloroplast membrane fraction consists of the lamellar membranes of the chloroplast. Such membranes consist of the following fractions:

- one chlorophyll protein complex I (28%),
- one chlorophyll protein complex II (49%), and
- five minor chlorophyll protein complexes (20%).

Mangan (1988) described the behaviour of the chlorophyll protein complex I in the rumen. The complex is insoluble in water. The behaviour of chlorophyll protein complex II in the rumen is unknown, though it is a component of the same membrane system as that to which chlorophyll protein complex 1 belongs, which means that its behaviour might, thus, be closely related to that of the latter.

The other fractions of proteins include the cell walls, the nucleus and the mitochondrion. The levels of nuclear and mitochondrial proteins tend to be low in forages, constituting no significant part of the forage protein content (Thornton, 2001). The analysis of the fibre or cell wall which is present in forages is of major importance in ruminant nutrition, as diets often contain large amounts of forage, and the fibre fraction affects both feed intake and animal performance (Jung, 1997a). The protein which is found in the cell walls is largely insoluble, due to the bonds that exist between cellulose and extension. As a result, the cell wall proteins experience a slow rate of degradation, due to the fact that the cell walls remain largely intact after initial chewing, presenting a physical barrier which must be breached prior to effective colonisation (Zhu *et al.*, 1999).

6.1.2 Dried and conserved forages

Native pastures are still the most important feed source for both sheep and goats. Such pastures account for the largest share of the land surface of many countries in Africa and Asia. Grazing off-takes from such lands is subject to great variation. Poor flock management strategies entailing an increase in flock size, stocking rate, grazing period and duration, and rangeland management are the

main causes of continuous degradation of rangelands. In such cases, the biomass which is consumed by grazing animals might not be sufficient to match their nutrient requirements. Those farmers with such livestock are, therefore, obliged to integrate other local feed sources, which are, unfortunately, in many cases low in essential nutrients. Feed grains and other concentrates comprise the smallest feed category in the aforementioned countries, due to the high cost and seasonal availability of such concentrates. However, under conditions of drought, feed imports from other regions must be increased, resulting in greater quantities of concentrates being incorporated into livestock diets, as well as accompanying increases in the feeding costs involved (Salem *et al.*, 2004).

Crop residues are mainly fibrous materials that are by-products of crop cultivation. Whereas such feed sources, particularly cereal straws, provide the bulk of livestock feed, their nutritive value is often so low that farmers must supplement them with feed grains and other concentrates.

Most common crop residues, such as straws and stubble, have a low CP content, which is in the range of 2% to 5% for DM. Such a low content suggests a basic limitation in the value of some residues (e.g. in that of wheat and barley straw) in comparison with the borderline 6% to 7% dietary CP which is required for the promotion of voluntary feed intake (VFI). Most of the residues are deficient in fermentable energy, as is reflected by their relatively low organic matter digestibility, while also providing a limited number of minerals (Salem *et al.*, 2004)

Though the protein fractions which are contained in dried and conserved forages are the same, the behaviour of such fractions may vary. Such behaviour variations have been associated with those changes that occur when the forages are dried or conserved. Forage digestibility and intake is greatly affected by the storage and preparation thereof. The intake and digestibility of green forage, when such forage is provided indoors, largely depends on its nutritive value, fill effects and sensory properties, assuming that such forage does not contain toxic compounds. The conservation of forage generally modifies its nutritional value. Compared with the conservation of the original green forage, its conversion to hay is related to a depression in its nutritive value and thus, also, to the intake thereof. The production of silage does not alter the digestibility of such forage, though its ingestibility is depressed if the quality of conservation is poor and the silage contains large amounts of fermentation end-products (Baumont *et al.*, 2000).

During haymaking, drying or wilting might cause changes to the digestive process. Drying, or any heating whatsoever, permanently precipitates the chloroplastic and cytoplasmic proteins, with the end result being that either none, or little, of the protein in the hay is water soluble (Thornton, 2001). Furthermore, during field drying, the forage proteins are broken down by the action of plant protease enzymes, which means that the AA composition of the dry and fresh forage may vary.

Two of the most common residues used in small ruminant formulations are cereal straw and stubble, both of which are discussed below.

6.1.2.1 Cereal straw

Straw corresponds to the residue (consisting of leaves, awns, and stems) which remains after the mature crops (i.e. grain) have been harvested. Straw might have high market value in times of drought and other harsh conditions when roughage is scarce and grain has to be imported. In Tunisia, for example, the sale price of straw bales has been reported to increase threefold to fourfold in drought periods, compared with the price which can be obtained for such bales during periods of good harvest. Cereal crop residues are used as an energy source in the form of digestible fibre for ruminants. Such crop residues should be accompanied by small amounts of suitable nitrogen supplement, which is contained in such feed as oilcake. If the nutritive value of the feed is low, or the desired level of production is well above maintenance, farmers should add an energy supplement, such as cereal grain, to the feed to help ensure the biological and economic efficiency of the livestock. However, it must be borne in mind that such supplemental feeds are often more expensive than are crop residues. Improving the nutritional value of straw and the efficiency of its use in mixed diets is a sound option by means of which to increase livestock production (Salem *et al.*, 2004).

6.1.2.2 Stubble

Stubble, which refers to that residue which is left after grain harvesting and straw collection, includes stems, small portions of leaves, grain and weeds. Although stubble provides important biomass for ruminant animals, its feeding value and any strategy for efficient integration of the material into livestock feeding have, as yet, not been adequately researched. The botanical and chemical composition of stubble varies greatly, in line with the grazing period. Large amounts of grains tend to be available at the beginning of a grazing period. One study into the changes in nutritive values of stubble grazed by ewes showed that mainly the CP and energy content decreased with the number of weeks spent grazing. The CP content of the stubble was found to be below 5% DM, with the crop residue being high in fibre (Salem *et al.*, 2004).

6.2. *Processed protein sources*

Processed proteins, consisting of both plant and animal type, are some of the most important protein sources in South Africa for ruminant nutrition. Most such proteins are industrial by-products, with substantial variation occurring in the related processing methods (Thornton, 2001).

6.2.1 Plant protein

Plant protein by-products include oilcake, consisting of sunflowers and soybeans. The oilcake meals are the products remaining once most of the oil has been removed from the oilseeds by means of either physical or chemical treatment. Oils are either forced out of the oilseed under high pressure or else are extracted using an organic solvent, such as hexane. Such processes are extreme, often poorly controlled and induce changes which alter the protein structure of the oilseed, possibly even rendering the plant protein source indigestible to the animal to which it is fed (Thornton, 2001). Such meals, however, are rich in protein, forming a valuable protein source for livestock (McDonald *et al.*,

2002). Such processes are usually carried out so as to render the protein source either partially or totally undegradable in the rumen.

Table 1.1 Nutritive values of soybean and sunflower meal (Moran, 2005)

Feed	DM ¹ (%)	CP (%)	CF / NDF (%)	ME (MJ/kg DM)	TDN (%)
SBM ²	91	48.7	6.2	14	86
SFM	94	52.4	5.7	12	75

¹DM = dry matter; CP = crude protein; CF = crude fibre; ME = metabolisable energy; NDF = neutral detergent fibre; TDN = total digestible nitrogen; ²SBM = soybean meal; SFM = sunflower meal.

6.2.1.1 Soybean meal oilcake

The utilisation of SBM oilcake as a protein source in animal feeds is well established, with rations supplemented with SBM being proved satisfactory both in feeding regimes and in experimental nutrition research (Stake *et al.*, 1973). The protein evaluation systems assume that the protein requirements for ruminants are met from microbial protein and undegraded dietary protein (UDP) that are digested in the small intestine. To achieve maximum productivity from high-producing or rapidly growing ruminants, better quality protein is required than that which is provided by rumen micro-organisms. UDP requirements tend to increase in line with the improved performance of the animal concerned. Such protein can be supplied by reducing the ruminal degradation, and by thus increasing the amount of protein that is digested post-ruminally. Full-fat soybean, which contains 40% CP and 17% fat, is valuable as a source of protein and energy in bovine rations during the initial stages of lactation, despite the protein which it contains being highly degradable in the rumen.

SBM is an excellent protein source, which can also contribute energy-providing fat to the diet. Soybean protein is rich in lysine, methionine, valine, and isoleucine, constituting the first, second, third and fourth AA limitation in productive cows (Nowak *et al.*, 2005). Griffiths (2004) found that SBM, in addition to being an excellent source of lysine, is also a rapidly degradable protein source. The protein content of soybean tend to be 75% to 80% degraded in the rumen (Broderick *et al.*, 1988; Promkot & Wanapat, 2003), which restricts its inclusion in diets for high-yielding ruminants. Although SBM protein is degraded relatively rapidly in the rumen, much of such a protein tends not to be digested in the rumen, thus making it available for enzymatic digestion in the small intestine (Khorasani *et al.*, 1990). Lu *et al.* (1990) found that SBM tends to be less utilised than is meat and bone meal (MBM), despite the degradation in the rumen being higher for SBM. Loerch and Berger (1981) found higher gains among SBM-fed steers than among those fed MBM.

The supplementation of diets with SBM in comparison with supplementation with more resistant protein sources has been shown to result in a decreased flow of the total amount of AA's and nitrogen in the duodenum of dairy cows (Ceava *et al.*, 1990). Heating SBM above the optimum temperature might protect such meal against microbial degradation in the rumen, as well as making its protein

content indigestible in the intestine, as a result of the Maillard reaction, which occurs between sugars and proteins (Loerch & Berger, 1981; Hadjipanayiotou, 1994; Nowak *et al.*, 2005). (For further explanation of the Maillard reaction, see subsection 6.2.2 below.) Aufrene and Graviou (2001) found that nitrogen from heat-treated feeds tended to degrade relatively slowly in the rumen, with SBM showing a reduction of 30% nitrogen in the rumen, compared with other protein feed sources. Improvements in the digestibility of CP and/or AA's in the small intestine have been reported for ruminants which were fed roasted and extruded soybean (Aldrich *et al.*, 1997). Although treated SBM tends to be a source of more AA's in the lower gut, Schmidt *et al.* (1973) found that those steers which were fed an SBM-supplemented ration tended to grow faster than did those steers which were fed a basal ration which was supplemented with treated SBM, urea or starea (consisting of an expansion-processed mixture of grain, starch and urea).

Hadjipanayiotou (1994) found that the response to a diet which was supplemented with treated protein tended to be better than was the response to a diet which did not meet the prescribed energy and protein requirements. Such a finding indicates that the feeding of protein sources which, in combination, are resistant to ruminal degradation might improve the profile of AA's in the intestine (Ceava *et al.*, 1990; Demjanec *et al.*, 1995).

To maximise growth performance, dietary protein from basal ingredients or protein supplements must escape rumen degradation and be available for absorption in the small intestine (Loerch & Berger, 1981). However, Stokes *et al.* (1988) found that the ruminal fluid dilution rate increased linearly and that the particulate passage rate increased with the inclusion of more SBM in bovine diets. The true ruminal digestibilities of organic matter, NDF and nitrogen also increased significantly with the inclusion of more SBM in the diet (Stokes *et al.*, 1988).

6.2.1.2 Sunflower meal (SFM) oilcake

In South Africa, SFM oilcake is a prominent plant protein source in animal feeds. Inclusion levels are unfortunately limited, due to the high rumen degradability of such meal (Griffiths, 2004) (Table 1.1). As the nutrient composition of SFM content appears to differ greatly between sources, such variations should be taken into account when feed comparison studies are conducted.

Although protein meals have been studied extensively in the case of non-ruminant animals, they have received little attention as a source of protein for ruminants. However, SFM is known to be deficient in lysine, though it contains approximately twice as much methionine as does SBM, which potentially makes it an excellent source of protein for growing ruminants (Amos *et al.*, 1974). As methionine is the first limiting AA in microbial protein for lambs, an increase in such an ingredient should increase lamb performance. Although SFM provides higher methionine levels than does SBM, Shirley (1986) found the two protein sources provided equivalent protein quality when fed to growing and lactating ruminants.

The degradation rates of SBM and SFM must be taken into account when comparisons are made. Protein with low degradation is especially valuable to those ruminants, such as early-weaned lambs,

which have high protein requirements. Broderick *et al.* (1988) found that SBM, at 79%, was more degradable in the rumen than was SFM, at 59%. Recently introduced feeding systems tend to emphasise the need for quantification of ruminal protein degradation, making it necessary to be able to assess the degradation of feed proteins both rapidly and accurately.

In a study which was aimed at assessing the nutritional value of SFM in cattle, it was reported that finishing steers fed SFM showed equivalent gains, feed efficiency, dressing percentages and carcass grades to those which were fed cottonseed meal (CSM) based on the CP level. In growing calves, SFM and SBM have been found to be equivalent in terms of animal performance. Shirley (1986) found that SFM and SBM were equivalent as protein supplements for lactating cows. Though the VFA proportions were unchanged, the pH of the rumen fluid tended to be lower in those cows which were fed SFM. In diets which were fed to growing-finishing steers, SFM and CSM were found to be equivalent in value on a protein basis. No differences in digestibility or nitrogen retention were observed at levels of 0%, 5.5% and 11% SFM in diets when it was substituted for equal amounts of CSM on a protein basis. When lambs were fed SFM, CSM, or a combination of such protein sources in 8% and 12% CP growing-finishing diets, those lambs which were fed the diets containing 12% CP had similar gains and feed efficiencies. Lambs fed formaldehyde-treated SFM retained a higher percentage of dietary nitrogen than did those lambs which were fed formaldehyde-treated SBM (Shirley, 1986).

Although SFM has been established as a main protein source in animal nutrition, its importance as a high-quality feed by-product is also increasing. Worldwide production of sunflower seeds is extensive, with sunflowers being ranked the fourth most widely produced oilseed producers (Zhang & Parsons, 1994). Sunflower seeds, which vary in their chemical composition depending on their cultivar, soil characteristics and climatic conditions, when processed according to different methods, can result in SFM with extremely diverse properties. In spite of such wide variation, on average SFM contains 30% to 40% CP, 13% to 15% CF, and 11.8 MJ ME/kg.

As a protein supplement, SFM might replace SBM in the rations of growing and fattening lambs, with similar gains and feed efficiencies. Stake *et al.* (1973) found that SFM-fed calves tended to be more efficient during the first eight weeks of feeding, which might indicate a more efficient feed utilisation for gain. Economides and Koumas (1999) found no differences between SFM and SBM in lamb-fattening diets in terms of the digestibility of CP, CF and ADF; though the digestibility of DM, OM, NDF and NFE was found to be lower with the SFM-based diet.

Irshaid *et al.* (2003) found that lambs which were fed SFM as a main protein source gained numerically less than did lambs fed SBM. Although the values for average daily gain and average total weight gain were similar, the average daily gain was higher for SBM-fed lambs. The end results showed that lamb performance based on gains and feed efficiencies were similar for SBM and SFM. Due to such results, it was concluded that SFM can be incorporated into the ration of lambs and ewes without any adverse effects on the digestibility, voluntary intake and growth of the animals concerned. SFM may be used as a protein supplement for sheep fed with SBM, or even in place of SBM, depending on the former's availability and price.

6.2.2 Animal protein

Processed animal protein sources include fishmeal, carcass meal and bone meal. Such animal proteins are derived from such sources as enzymes, membranes, transport proteins (albumins) and/or muscle (myoglobin). The degradation properties between different animal proteins vary to a large degree (Thornton, 2001), possibly depending on the induced changes which occur during processing. Though, in the case of heat, coagulation or denaturation merely reduces the degree of protein solubility or accessibility, the results which are obtained with the Maillard reaction might be more detrimental in terms of altering protein structure. The Maillard reaction can occur not only in fishmeal, but also in other feed sources, either at a mild or high temperature. The reaction involves proteins and other components, normally carbohydrates, which are contained in a feed. Lysine is often affected by the Maillard reaction when the amino group and the sugar aldehyde group of glucose react. The end result is that, though the AA is absorbed by the animal, it, nevertheless, remains unavailable in the body, being eventually excreted in the urine. In animal proteins, the objective of heat or chemical treatment is to slow down the rate of degradation in the rumen, thus increasing the probability that the protein is transported through to the small intestine.

In July 1994, a ban was placed by the European Union (EU) on the use of MBM in feed for ruminants (EC, 1994). Feed contaminated with MBM was accepted to be the main transmission carrier of the prion which was found to have been responsible for causing the development of bovine spongiform encephalopathy (BSE) in the European bovine herd (Baeten *et al.*, 2005). As an additional preventive measure against the spread of BSE, in 2001 the EU totally suspended the use of processed animal proteins in feed for any animals farmed for the production of food (EC, 2001). The only exception to such bans has been in the case of fishmeal used in feeds for non-ruminants (O'Rourke, 2005). South Africa and other developing countries which participate in international agricultural trade are obliged to adopt all universally established control systems at all stages of production and in all sectors of the industry. For example, as an exporter of most of its meat products to European countries, South African producers have also been directed to use little, or no, animal protein in their livestock diets.

7. Factors influencing the solubility of proteins

The solubility of protein sources varies, being subject to the influence of numerous factors. The pH of such sources definitely affects protein solubility, as does the chemical nature of the protein concerned. Proteins are ampholytic (meaning that they are able to act as an acid or base), and electrostatic bonding between ions of opposite charge plays an important role in maintaining stability. The solubility of proteins is lower at a pH of 5.5 than it is at a pH of 6.5 or 7.5, though no differences in solubility appear to exist at higher pH values.

Ionic strength also affects the solubility of proteins. As a result of the interactions that occur between the charged groups of the protein molecule and the ions of dissolved salts, many proteins, which are insoluble in pure water, have the capacity to dissolve in the presence of small amounts of neutral salts. Thus, in the presence of ionic fluids in the rumen, protein solubility levels might increase. The

effect of temperature on protein solubility is variable, and not always predictable. The solubility of some proteins decreases with a change in temperature, while that of other proteins might increase (Cronje, 1983 as cited by Thornton, 2001).

7.1 Protein characterisation

Nowadays, a range of protein sources is commercially available for inclusion in animal feeds, so that the decision as to which such source to use can be a complex one. A thorough understanding of farming conditions should facilitate the decision-making process. For example, the protein needs of animals grazing on green fertilised pastures differ from those of animals grazing on dry land. Mehrez and Ørskov (1978) found that protein supplementation increased the feed intake, the live weight gain and the feed conversion ratio in sheep. Protein sources utilised in concentrate diets are intended to complement prevailing farming conditions in order to optimise production and, ultimately, profitability. Important information required for the assessment of protein sources includes (Thornton, 2001):

- the method by which the source has been processed;
- the AA profile of the source; and
- the potential of the source to complement microbial protein in the small intestine of the animal feeding on such a source.

7.2 Protein degradation and digestion

The supply of protein which is intended for absorption by the intestinal tract of the ruminant is influenced by the ruminal degradability of the dietary protein concerned, as well as the production of microbial protein. Predicting the amount of dietary protein to reach the intestinal tract and the degree of synthesis of microbial protein from digested protein is the goal of many protein systems (Garrett *et al.*, 1987).

Dietary protein, which is also referred to as CP or dietary CP, can be defined as the nitrogen content of the feedstuff multiplied by 6.25, which is a factor derived from the average nitrogen percentage of vegetable protein. The main purpose of dietary protein is to provide AA's, which are the main building blocks for protein synthesis in rumen animals (Zhu *et al.*, 1999; Griffiths, 2004). Stern *et al.* (1994) have shown that protein supplements tend to provide approximately 46% of the total CP in the diet of ruminants, so that the quality of undegradable protein could profoundly affect individual AA supply to the small intestine.

CP can be divided into three fractions, consisting of (1) true protein; (2) NPN; and (3) acid detergent insoluble nitrogen (ADIN). True protein can be subdivided into an RDP fraction and a rumen-undegradable protein (RUP) fraction, which have distinctly different functions. The former fraction is broken down by rumen microbes into ammonia, energy and carbon fragments, which provide for the needs of rumen microbes. The microbes, in turn, supply the ruminally synthesised microbial protein, which provides most of the AA's which pass into the small intestine of the animal concerned. However, many of the fibre-degrading cellulolytic species in the rumen are not proteolytic, with the proteolytic activity of the entire rumen microbial population being only moderate in comparison with the gastric and pancreatic secretions which are present in the abomasums (Zhu *et al.*, 1999).

The NPN fraction is either absorbed by the animal concerned, thereafter being recycled or retained in the tissues as milk, or it is excreted in the faeces and urine. In addition, such a fraction can be used by certain rumen microbes. ADIN refers to those nitrogenous compounds which are bound up into the lignified, totally indigestible portion of the cell wall, and which are, thus, unavailable for degradation in the rumen or in subsequent acid digestion. The fraction concerned is excreted as nitrogen in the faeces.

The pool of potentially fermentable protein not only consists of dietary proteins, but also includes the endogenous proteins of the saliva, sloughed epithelial cells and the remains of lysed rumen micro-organisms. All of the enzymatic activity of ruminal protein degradation is of microbial origin. Peptides have to be broken down to AA's prior to their use by certain microbes. Thus, both the peptides that escape ruminal degradation and the free AA's which are not used by the microbes ultimately flow through to the abomasum (Griffiths, 2004).

Bacteria are the most abundant of the micro-organisms in the rumen, and are also the most involved in ruminal degradation. The initial step in protein degradation by ruminal bacteria consists of the adsorption of soluble proteins by the bacteria concerned. Bacteria cannot distinguish between different sources of nitrogen for protein synthesis. Microbial protein supplies approximately 66% of the ruminant's AA requirements, whereas dietary protein sources account for most of the remaining requirements. Digestion finally yields free AA's, which continue onwards towards the small intestine, where they are absorbed for use in the metabolic processes of the different tissues of the animal, including the mammary gland, where the final products are formed. RUP is the second most important source of absorbable AA's for such an animal (NRC, 2001 as cited by Griffiths, 2004).

The AA passage to, and absorption from, the small intestine depends on the amount of protein which is consumed, on the extent of ruminal degradation of the protein concerned, and on the synthesis of microbial protein (Griffiths, 2004). Originally, it was assumed that the degradability of a given feed was constant. However, such was later shown not to be the case, as high-producing ruminants have a higher intake, resulting in a faster rate of feed passage and a shorter retention time in the rumen. The protein is, therefore, exposed to the rumen microbes for a shorter period of time, with a smaller fraction thereof consequently being degraded. For some feeds, such as SBM, the retention time of the feed in the rumen alters the degradability of the protein considerably. The extent of protein degradation also depends on the amount of microbial activity and the degree of access to the protein. Proteins with extensive cross-linking properties tend to be relatively resistant to degradation. Such feed processing methods as extrusion might generate sufficient heat to alter the original protein structure.

Soluble proteins tend to be more rapidly or completely degraded than are insoluble proteins. Access to protein by proteases tends to be relatively high if the protein is in solution. Unfortunately, protein solubility as a measure of protein degradation can lead to serious errors when such a measure is applied to a variety of feeds. Nonetheless, the extent of protein solubility can reasonably be expected to predict differences in protein degradation more accurately when such a measure is applied to a group of similar feeds than when it is applied to a diverse group, which varies in both physical and

chemical properties. Variations in protein degradation within a feed can be extensive, such as the variation which is due to differences in processing conditions, which can affect the extent of protein degradation. Variation from one feed supplier to another can also be significant (Griffiths, 2004). However, Mehrez and Ørskov (1978) found that supplementation with a small amount of protein improved both the degree of VFI and the growth rate of sheep. A direct result of adding protein to feed is the increased rate of digestion observed. Huston *et al.* (1986) and Jones *et al.* (1972) found that the digestibility of diets fed to sheep and goats was moderate. Their results suggested that the rate of digestion was related more to diet than to the animal species which consumed that diet. However, Reid *et al.* (1990) and Gihad and El-Bedawy (1980) showed that the digestibility differences between goats and sheep significantly favoured the digestibility of goats.

Although a constant periodic influx of digesta into the intestine is typical of a simple-stomached animal, the passage of the digesta from the reticulo-rumen and omasum is a continuous process. Hence, in ruminants, the digesta that reach the intestine are of more uniform composition, depending less on the kind of food ingested than do the digesta in simple-stomached animals. The former digesta largely consist of microbial protein, containing only miniscule amounts of carbohydrates, since most of the latter have been digested, and their metabolites absorbed, in the rumen (Ben-Ghedalia *et al.*, 1974).

Many factors, therefore, influence the degradability of any protein source (Griffiths, 2004). Broster (1973) reported that additional protein might increase the apparent digestibility of protein in a ration, whereas additional energy might depress it. The effective degradability of a given feed depends on the production level of the animal concerned, and thus on the rate of outflow, as well as on the specific degradability pattern for that particular feed (Griffiths, 2004). Even in living cells, proteins are in a continual process of turnover, with the balance between synthesis and degradation resulting in net protein content. The rate of turnover of individual proteins also depends on their function and role within the cell, as well as on the physiological status of the cell (Zhu *et al.*, 1999).

7.3 Treatment of protein sources

Feedstuffs can directly contribute to the AA requirements of ruminants by providing a source of absorbable bypass AA's, or indirectly as a source for use in microbial protein synthesis. Such comparisons are useful for assessing the value of a certain amount of bypass protein from one feedstuff in relation to the value of the same amount of such protein which is obtainable from another feedstuff.

Lysine and methionine tend to have the greatest effect on the value of a given quantity of bypass protein, because the two AA's in question are often considered to be first limiting for production. The intestinal digestibility of bypass AA's is also a factor when determining the value of bypass protein. The level of bypass AA's in the feedstuffs must, therefore, be considered of equal importance with the AA profiles of the feed and their intestinal digestibility (O'Mara *et al.*, 1997).

Those protein-containing feeds which have been processed so as to decrease ruminal protein degradability in order to increase the content of digestible RUP are frequently termed “rumen protected”. The Association of American Feed Control Officials has defined “rumen protected” as characterising “a nutrient(s) fed in such a form that it provides an increase in the flow of that nutrient(s) unchanged, to the abomasums, yet so that it is available to the animal in the intestine” (Griffiths, 2004).

The protection of protein against rumen degradation results in more AA's being available in the small intestine. Such greater availability of AA's implies a higher ratio of absorbable AA per unit absorbable energy, which should ultimately lead to a positive response in production, should the animal have a requirement for, or be able to use, more AA's. That protein passes through the rumen does not necessarily mean that such protein can be digested efficiently, or that it has the correct AA profile (Griffiths, 2004).

In attempting to establish a protein degradability database for those protein sources which are generally used in South Africa, Griffiths (2004) showed that heat-treated protein sources had a lower soluble nitrogen fraction than did unheated protein sources. Heating can, thus, be applied as a method of protecting protein from rumen degradation

8. Factors Influencing Protein Degradation

Protein solubility and differences in protein structure (resulting from disulphide bridges and cross-linking) appear to be important factors in the ruminal degradation of protein. When the principal protein fractions are albumins and globulins, the solubility of the relevant protein tends to be higher than it is with feeds containing mainly prolamins and glutelins. The solubility of protein in feedstuffs is affected by the pH of the feedstuffs concerned. Drying of forages in the field allows proteases to become active, which increases protein solubility. Some carbohydrates and proteins are degraded during silage-making due to fermentation, which results in the nitrogen-containing end-products of the fermented protein occurring in the soluble fraction concerned. Essentially, all of the soluble nitrogen, as well as 40% to 50% of the insoluble nitrogen, is degraded in the rumen. The extent of protein breakdown is a function of the rate of proteolysis and the retention time in the rumen. Retention time is influenced by the particle size of the diet components and the level of feed intake. Tamminga (1979) studied the effect that the level of feed intake had on protein breakdown in the rumens of dairy cows equipped with re-entrant cannulae in the small intestine. The cows were fed mixed diets of hay and concentrates, containing three levels of protein and two levels of feed intake. The six diets contained 30% soluble protein. At the low level of feed intake, 26% of the total dietary nitrogen and 37% of the insoluble dietary nitrogen was found to escape degradation in the rumen. At the high level of feed intake, the corresponding values were 42% and 60%, respectively. Retention time in the rumen varies from one diet to another, between animals of the same species, as well as between animals of different species. Rumen retention times from 1.3 to 3.7 days have been reported for cattle, and from 0.8 to 2.2 days for sheep. Though fluid retention time is usually much shorter, it is also probably affected by the rate at which food particles pass through the rumen.

8.1 Rumen metabolism

Merchen *et al.* (1986) found that such dietary variables as intake and forage level tend to interact and affect ruminal metabolism. The rate and extent of protein degradation in the rumen affects microbial protein synthesis and determines the quantity of UDP which reaches the duodenum. The extent to which protein is degraded primarily depends upon microbial proteolytic activity in the rumen, microbial access to the protein, and the ruminal retention time of the protein concerned. Other factors influencing protein degradation include protein solubility and ruminal pH. Protein structure influences accessibility to proteolytic enzymes, thereby affecting the degradability of protein in the rumen. Some dietary feed ingredients are naturally resistant to ruminal microbial degradation; however, other feeds may have a greater or lower resistance to microbial degradation, due to physical processing (Stern *et al.*, 1994).

Factors determining the extent of degradation occurring in the rumen include the rate of digestion, the rate of passage, the amount of protein ingested, and the solubility of the protein in the rumen fluid. Such units, individually, play a significant role in the amount of protein which is degraded in the rumen (Garrett *et al.*, 1987; Stern *et al.*, 1994). Reid *et al.* (1990) suggested that, compared with sheep, goats were better able to digest low-quality forages, possibly due to their longer ruminal retention times and to their greater capacity to recycle and conserve N. In contrast, Jones *et al.* (1972) found that goats and sheep did not differ in terms of their ability to utilise high-quality forages. Forage quality, which is a major determinant of rumen degradation, can, thus, be used to compare the digestive capacities of ruminant species (Larbi *et al.*, 1997).

8.2 Rumination

Re-chewing of food, or chewing the cud, is a characteristic of ruminants, which is closely associated with the feeding of herbage. The break down of resistant plant parts by rumination has been postulated as being essential for the complete action of microbial enzymes in reducing particle size. However, such a factor is probably minor when it is considered in comparison with the importance of rumination in reducing particles to a size that can proceed through the lower alimentary tract. A demonstration that very fine grinding increases the digestibility of cellulose in forage has indicated that rumination might, to some extent, increase fermentation (Shirley, 1986).

The partial separation of fine and coarse particles between the rumen and reticulum depends on the spatial configuration of the compartments concerned, as well as on their mixing contractions. Reticulum contents tend to be more liquid than are those of the rumen. Such greater liquidity is partly due to the presence of saliva, which is secreted into the reticulum during non-feeding periods and also partly due to the rapid reticular contractions which serve to expel the coarse materials into the rumen, in which they float. Slow contractions of the ventral sac of the rumen cause those liquids which accumulate around the mass of digested solids to spill over into the reticulum. Though some particles are carried along with the liquid, the main mass of the particles tends to remain behind in the rumen. The reticulum-omasal orifice is the site of the separation of coarse particles from fine (Shirley, 1986).

In those animals which are fed forages, the amount of undigested feed residue which can be accommodated in the rumen varies widely. There appears to be a direct relationship between the rumen digesta load and the energy deficit of such an animal, with the latter primarily being influenced by the amount of nutrients absorbed, as well as by the physiological state of the animal. In addition, the balance of absorbed nutrients also influences such an energy deficit. Accordingly, when restricted supplementation is provided, in the case of the provision of low-quality diets, the quality of the diets is increased, resulting in a higher intake of such diets. Such a principle applies to the supplementation of low-quality forages with essential nutrients. For ruminants, in a given physiological state, the rumen fill most commonly hardly varies. Thus, when grain products are included in those diets which are based on low- to medium-quality forages containing adequate microbial substrates, the changes occurring in voluntary forage intake are likely to result from changes in both the rate of rumen digestion of the forage components and in the rate of removal of feed residues from the rumen (Dixon & Stockdale, 1999) (Table 1.2).

The extent to which energy intake exceeds the requirements for maintenance determines the conversion efficiency of feed into animal products and, consequently, animal productivity. In those ruminants which are fed roughage, the regulation of voluntary intake depends, above all, on physical factors. The rate of fermentation and the fractional rate of passage in relation to the rumen volume are important factors in the physical regulation of such voluntary intake. Differences have been observed in voluntary intake and in the extent and rate of degradation between sheep and goats which were provided with low-quality roughage. An evaluation of the passage and fermentation rates of animals in pasturage is thought necessary in order to quantify the differences between animal species in relation to the fraction of the feed which is degraded in the rumen, as well as in order to explain variations in their feed intake (Garcia *et al.*, 1995).

Table 1.2 Comparison of mean reticulo-rumen retention times determined for sheep and goats for various forage particles

Animal	Retention time (h)	Reference
Sheep	32.7	Huston, 1978
	73.0	Faichney, 1975 as cited by Katoh <i>et al.</i> , 1988
	70.0	Van Soest, 1982a as cited by Katoh <i>et al.</i> , 1988
	92.0	Katoh <i>et al.</i> , 1988
Goat	22.0	Huston, 1978
	38.0	Van Soest, 1982a as cited by Katoh <i>et al.</i> , 1988
	48.0	Katoh <i>et al.</i> , 1988

Whereas the difference in retention times between sheep and goats has not yet been elucidated, the classification of ruminant animals proposed by Hofmann (1973) might offer a possible explanation. Hofmann classified ruminant species into three types, according to the structures of their stomachs and other features: roughage eaters (grazers); concentrate selectors (browsers); and intermediate adaptable feeders. Roughage eaters have a large reticulo-rumen and a long feed retention time, whereas concentrate selectors have a smaller reticulo-rumen and a shorter feed retention time. Longer retention times offer advantages in terms of fibre digestibility. Whereas goats belong to the intermediate adaptable feeder group, sheep belong to the roughage eater group. Such a classification system might partly explain the difference which has been obtained in results for sheep and goats, with such a difference possibly being associated with the movements of the reticulo-omasal orifice and the reticulo-rumen, as well as with their relative sizes (Katoh *et al.*, 1988).

9. Protein Requirements

In quantitative terms, protein is second in demand only to energy, constituting 20% of wet tissue (Thornton, 2001). The protein requirements of goats and sheep can differ, due to the fact that goats tend to select diets with higher protein content than do sheep (Garcia *et al.*, 1995) (Table 1.3). Alcaide *et al.* (1997) also found that goats tended to select diets with a higher protein and a lower fibre content than did sheep. The methods which are used for determining protein requirements are very important, with numerous systems having been developed over the years.

Table 1.3 Relative energy and protein requirements of sheep and goats (Huston, 1978)

	Sheep	Goat	Sheep	Goat
Body weight (kg)	¹ DE (MJ/day)	DE (MJ/kg)	DP (g/kg)	DP (g/kg)
Maintenance				
27		11.72		65
36		13.81		77
45		15.49		86
50	10.04		48	
54		16.74		91
60	11.3		53	
70	12.14		58	
80	13.39		63	
Lactation				
27		18.42		113
36		20.09		122
45		22.19		136
50	25.12		130	
54				
60	27.63		143	
64				
70	30.14		155	
73				
80	30.98		161	

¹DE = digestible energy; DP = digestible protein.

10. Conclusion

Worldwide, sheep and goats are a very important resource, contributing meat, milk and fibre products, as well as performing other functions which are significant to the productivity, stability and sustenance of many farming systems. Inadequate availability of quality feed is widely regarded as a major constraint to most of the prevalent small ruminant production systems in many parts of the developing world. Such systems are under pressure to switch over from traditional free-range functioning to stall feeding, due to rapidly expanding populations and ever-increasing land shortage. Therefore, small ruminants will have, increasingly, to be confined on farms and fed with on-farm available feeds.

The steadily increasing cost of protein and the spreading contamination of environmental pollution due to emission of ammonia into the atmosphere from the degradation of urea in excreta demand that optimum levels of dietary protein for animals be determined in order to avoid unnecessary loss of nitrogen, as well as in order to optimise production and minimise costs of feed and the increase in

those risks which are associated with environmental pollution. In contrast to the amount of information which is readily available on the nutrient requirements and the nutritive value of feedstuffs for sheep, the amount of corresponding information which is available on goats is limited (Negesse *et al.*, 2001).

Farmers have traditionally used such protein supplements as oilcake, bran and grain to improve the nutritive value of cereal straw. Each species of animal differs in its nutritional needs for achieving optimum growth and production potential. To achieve high productivity, each species' requirements for such protein sources as SBM and SFM should be examined in order to improve the nutrient utilisation of cereal straw provided.

Nutritional variation affects the productive abilities of ruminant animals differently. McGregor and Umar (2000), for example, found that those goats which consumed a pasture-based basal diet of low DE and nitrogen were affected, in terms of supplementation of feed, by:

- whether the feed was whole grain;
- the type of grain fed; and
- the level of feeding of grain.

The rate and extent of protein degradation in the rumen is crucial, as it determines the availability of nitrogen to the micro-organisms and AA's which are present in the small intestine of the host animal. The protein which is consumed by the animal should be partly degradable in the rumen, in the form of peptides, AA's and $\text{NH}_3\text{-N}$, which are derived from proteolysis, and which can be used in microbial protein synthesis. Ultimately, the rumen ecology can be improved. Determining the degradability and digestion of different feed ingredients which are used for growth in goats and sheep is, therefore, of great importance (Promkot & Wanapat, 2003).

Though information on the correlation between goats and sheep in regards to degradability and digestibility has been published in the past, there is still a shortage of published data on the topic, which is relevant to the improvement of farming conditions for meat (Boer) goats and Dohne Merino sheep. The objectives of the study which was described in the current chapter were, firstly, to compare the efficiency of diet utilisation of sheep and goats; and, secondly, to measure the rates of ruminal protein degradation of SBM oilcake, SFM oilcake and feeds which contained either high or low levels of fibre.

11. References

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CHAPTER 2

The Utilisation of High- and Low-Fibre Diets by Dohne Merino Sheep and Boer Goats, As Determined by a Digestibility Study

Abstract

The purpose of the trial was to determine whether the quality of the diet provided affected the feed intake and feed digestibility parameters differently in sheep and goats. In addition, differences in intake and digestibility parameters were evaluated within species. A 6 × 6 Latin square trial was conducted with Dohne Merino and Boer goat wethers. The wethers had *ad libitum* access to water and the diets were fed once daily at 1.24 kg/day. Each period consisted of ten days of adaptation and seven days of faecal and urine sampling. No significant differences were detected between the dry matter (DM), crude protein (CP) and metabolisable energy (ME) intake of goats and sheep for either the high-fibre (HF) or the low-fibre (LF) diet. However, the sheep showed a significantly ($P < 0.05$) higher neutral detergent fibre (NDF) intake for the HF in comparison with that of the goats. Within species, the HF significantly ($P < 0.05$) decreased the HF nitrogen intake in goats compared with the LF. Regarding DM digestibility, no interspecies differences were detected between the two diets. The intake and digestibility characteristics of nutrients were affected within species by the different quality diets. However, no differences were detected in either the digestibility or intake characteristics between sheep or goats on either the low- or high-fibre diets.

Key words: *ad libitum* feed intake; degradation; digestibility; wethers

Introduction

The consumption of native grasses and low-quality straw has been shown to limit the production potential of small ruminant animals (Norton & Waterfall, 2000). Most such forage has a high cell wall component, is deficient in nitrogen (N), and has a low digestibility and level of microbial activity. The native effects of diets containing low-quality roughage present themselves in the form of weight loss in mature animals and in suboptimal growth in younger animals. Different nutrients are present throughout the maturing stages of such low-quality roughage, inevitably affecting the productivity of the ruminants concerned (Brundyn, 2002).

The functionality of the rumen diets relies on the maintenance of its microbial population through the intake of feed by the animal. Optimal functioning of the ruminal microbial population not only improves digestion (Moir & Harris, 1962; Church & Santos, 1981), but also results in both a higher feed intake and the improved energy status of the ruminant.

Supplementation of low-quality roughages with protein can result in improved dry matter (DM) intake by ruminants, resulting in an increase in the passage of material through the alimentary canal to the small intestine (Church & Santos, 1981). A higher forage intake is correlated with an increase in digesta flow, digestion rate and the better digestibility of forage material, which ultimately results in an increased production rate (Delcurto *et al.*, 1990).

Although it is known that different small ruminant species differ in their abilities to utilise low-quality diets, comparative data in relation to the degree to which such animals differ from one another is currently lacking. One study by Alcaide *et al.* (1999) reveals that grazing goats were found to have a lower energy intake than did sheep, with the passage rate of particles from the rumen also being remarkably high. The objective of the study described in the current chapter was, thus, to determine the extent to which sheep and goats differ in their ability to digest either feeds. A further aim was to evaluate the extent of differences in the digestibility of low-fibre (LF) and high-fibre (HF) diets within the species itself.

Materials and Methods

Animals and conditions under which animals were kept

Six Dohne Merino sheep and six Boer goat wethers, with an average live weight of 80 kg (\pm 5.22 standard deviation [s.d.]) and 60 kg (\pm 4.06 s.d.), respectively, were used in a 6 \times 6 Latin square design to evaluate the intake and utilisation characteristics of low- or high-fibre feeds. Prior to the trials, ethical approval was obtained by the Division of Research and Development, Stellenbosch University (Ref. no. 2006B03005) to conduct such trials. The trials were carried out at Stellenbosch University's Experimental Farm, which is set in Welgevallen, South Africa. All test animals were first dewormed with a broad spectrum drench to eliminate all internal parasites before the commencement of the trials. The animals were housed individually in 1 \times 2 m metabolism crates, and had *ad libitum* access to feed and water. Each animal was randomly assigned to one of two treatments, consisting of either an HF or an LF diet (Table 2.1).

Feed preparation

The feed was chopped into 25-mm pieces with a hammer mill and offered at 90% of *ad libitum* intake. *Ad libitum* intake was determined during the 10-day adaptation period at 1.78 kg/d (\pm 0.74 s.d.) for the sheep and 1.31 kg/d for the goats (\pm 0.92 s.d.). The animals were fed once daily at 08:00. The main formulation differences between the diets consisted of the higher levels of oat hay (356 g/kg) which were included in the HF diet compared with the LF diet, which contained 204 g/kg oat hay. The differences between the inclusion of maize (306 g/kg in the HF diet and 458 g/kg in the LF diet) and wheat (102 g/kg in the HF diet and 152 g/kg in the LF diet) affected the nutrient composition of both diets. 34 g/kg of Mutton Gainer 125, consisting of protein, urea, trace minerals and vitamins, was also included in the diets, which resulted in a higher neutral detergent fibre (NDF) and crude fibre (CF) content and in a lower crude protein (CP) content.

Sampling

The trial consisted of two periods of 17 days each. The animals concerned were allowed to adapt to both diets for the first 10 days of each period. During the first period, all the animals were fed on the HF diet, whereas throughout the second period all the animals received the LF diet. During the following seven days of each period, 90% of *ad libitum* feed intake was measured. Orts were removed before the morning feeding and kept as individual samples for every animal for the duration of each period. Faeces were collected quantitatively each day, with a representative sample of 10% of such faeces being stored in plastic bags in a deep-freezer at 20 °C until undergoing analysis.

Chemical analysis

Faecal samples were dried in a drying oven for 96h at 60 °C. Feed, orts and faecal samples were ground with the use of a Scientec hammer mill (Peter Rassloff, Instruments & Services (Pty) Ltd.) so that it could pass through a 2-mm screen. All the faeces and ort samples were pooled for each animal and in respect of both diets in order to obtain a representative sample for each animal and treatment for the duration of the entire experimental period. One representative feed sample was formed for the study. Proximate analysis was carried out on all the samples obtained. The energy which was present in the urine and methane was subtracted from the amount of digestible energy (DE) which was present in order to calculate the amount of metabolisable energy (ME) which was found to be present. The amount of methane was estimated as being 8% of the gross energy intake (McDonald *et al.*, 2002) available. Nitrogen and NDF analyses were undertaken according to those methods prescribed by the Association of Official Analytical Chemists (AOAC; 2002). The nitrogen was measured with a Leco FP-428 Nitrogen and Protein Analyser (Leco Corporation, 3000 Lakeview Avenue, St. Joseph, MI 49085-2396). After drying the faecal samples, orts and feed at 60 °C in a convection oven, the amount of DM, apparent CP and apparent NDF digestibility present was determined (AOAC, 2002).

Statistical analysis

Intake and digestibility data were analysed as a 6 × 6 Latin Square, using the one-way analysis of variance (ANOVA) procedure of Minitab and Tukey's multiple comparison tests, with effects for animal, period and treatment being recorded. The significance level was set at P < 0.05.

Table 2.1 Physical and chemical composition of the two diets fed to the Dohne Merino and Boer goat wethers

Physical composition¹	HF (g/kg)	LF (g/kg)
Maize meal	306	458
Wheat	102	152
Lucerne chopped	152	102
Oat hay chopped	356	204
CSM cake	50	50
Mutton Gainer 125	34	34
Chemical composition²		
DM	860	820
Ash	71	69
CP	121	133
NDF	393	248
CF	150	88
Fat	15	18

¹On air-dry basis; CSM = cottonseed meal; DM = dry matter; CP = crude protein; NDF = neutral detergent fibre; CF = crude fibre; ME = Metabolisable energy; ²Analysed values on a DM basis

Results and Discussion

In the study described in this chapter, the utilisation of HF and LF diets by Dohne Merino sheep and Boer goats was compared. The main formulation differences between the two diets which were fed were the levels of oat hay (356 g/kg in the HF diet, compared with 204 g/kg in the LF diet), and the inclusion of maize (306 g/kg in the HF diet, or 458 g/kg in the LF diet) and wheat (102 g/kg in the HF diet, or 120 g/kg in the LF diet), which affected the nutrient composition of both diets.

Intake of forage-based diets

In the study described in this chapter, the CP content of the HF and LF diets was 121 g/kg and 133 g/kg, respectively. Diets containing CP levels lower than 70 g/kg have been reported to restrict optimum rumen fermentation (Tagari *et al.*, 1964; Mekasha *et al.*, 2002; Salem *et al.*, 2004), as suboptimal CP is then made available to the rumen microbial population (Hannah *et al.*, 1991).

In the current study, the HF diet contained 39.9% NDF, whereas the LF diet contained 24.8% NDF. Teferedegne (2000) found that feed containing 20% to 30% NDF was generally regarded as containing a low level of fibre. Therefore, the HF diet which was used in the current study had a higher level of fibre than did the LF diet. Various researchers have found that the main dietary factor which limits the intake of forage-based diets is the concentration of NDF, and that ruminants consuming low-quality forages often fail to have their nutrient requirements for growth met. Mekasha *et al.* (2002) found that sheep tended to have a lower feed intake of pulse hulls (ranging from 41% to 71% NDF) compared with their intake of lentil hulls (49% NDF). A sufficient supply of the correct nutrients can assist to optimise low-quality feed composition (Salem *et al.*, 2004). The chemical composition of both diets is represented in Table 2.1.

The mean feed DM, nitrogen, energy and NDF intake of the diets of Boer goats and Dohne Merino sheep is presented in Table 2.1. In the current study, no significant difference ($P < 0.05$) was found between the DM intake of goats and that of sheep consuming the LF or HF diet. Such observations are consistent with the work of Ferrell *et al.* (1999) and Doyle *et al.* (1984), who reported that the DM intake was the same for both low- and high-quality diets fed to goats and sheep. Reid *et al.* (1990) and Jones *et al.* (1972) found similar results in relation to the DM intake when they performed a comparative utilisation study between goats and sheep. In contrast to the findings of such a study, Molina-Alcaide *et al.* (1997) stated that they found goats to be significantly superior in terms of their DM intake, in comparison with the DM intake of sheep which were fed on low-quality pastures.

Table 2.2 Feed intake by sheep and goats fed HF and LF diets

	LF diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
DM intake (g/day)	1164.70 ^{ab} ± 312	1458.70 ^b ± 243.40	852.70 ^a ± 192.40	1197.30 ^{ab} ± 73.70
N intake (g/day)	156.01 ^{ab} ± 41.91	191.63 ^b ± 3.19	112.07 ^a ± 22.64	146.05 ^{ab} ± 8.99
ME (MJ/day)	17.25 ^{ab} ± 4.61	21.61 ^b ± 3.604	12.07 ^a ± 2.72	16.94 ^{ab} ± 1.043
NDF intake	326.13 ^a ± 87.35	408.45 ^{ab} ± 68.14	503.10 ^b ± 113.49	706.39 ^c ± 43.49

Data with common superscripts were not found to differ ($P < 0.05$) from one another. Standard error of mean is indicated as \pm .

In the current study, it was found that intake increased as the dietary CP level increased. The nitrogen and energy intake was not found to differ significantly ($P > 0.05$) between goats or sheep in the study. Although no significant differences ($P > 0.053$) were found in CP intake between the diets in the study, a tendency towards higher intake of the LF diet was detected. Such a result is supported by the significantly ($P < 0.05$) higher CP digestibility in goats which were fed the LF, rather than the HF diet. Such a finding indicates that additional protein is required to optimise the intake of low-quality diets. Ammerman *et al.* (1972) also found that the intake and digestion of low-quality roughages by ruminants was greatly affected by the nitrogen intake of such roughage.

In ruminants, feed intake is regulated by dietary energy density. Lu *et al.* (1990) found that DM intake decreased as dietary energy density increased, and that DM intake was influenced in a linear fashion by the dietary CP level. The voluntary intake of low-quality feeds might be increased by adding 1 g or more of soybean meal (SBM) to the feed (Church & Santos, 1981). Stokes *et al.* (1988) showed that the increase of DM intake, when SBM was provided, was due to small increases in the level of ruminal digestion, implying that metabolic regulation modified the intake of the low-quality forage concerned.

In the current study, the sheep showed a significantly higher difference ($P < 0.05$) in NDF intake from the HF diet when such intake was compared with that of goats, possibly due to the NDF content (39.3%) of such diets, which might have enhanced the efficient performance of rumen micro-organisms, resulting in the improved intake thereof (Ammerman *et al.*, 1972). Mehrez and Ørskov (1978) showed that growth rate and voluntary feed intake (VFI) increased when sheep rations were supplemented with small amounts of protein. Goats, in contrast, showed greater differences in their levels of digestibility compared with those of sheep, due to their capacity to digest the CP content of the HF diet, rather than the NDF content (Gihad & El-Bedawy, 1980; Reid *et al.*, 1990). Egan and Doyle (1985) found that a feed which contains a relatively high CP content might affect the intake of nutrients. The higher NDF intake observed for the HF diet for sheep relative to the entire NDF intake for the goats and sheep might be due to a non-parallel distribution of data resulting from the large variation which was reflected by the collected data points. Two goats continuously showed signs of diarrhoea on the LF diet, possibly due to stress which was caused in the metabolic crates during

feeding. The relatively high NDF content which was detected with the HF diet might have led to an increase in the NDF intake of sheep.

The relatively high NDF intake for sheep can also be explained in terms of the results which were obtained by Isac *et al.* (1994) and Lu *et al.* (1990), who found an increased outflow rate from the rumen in goats compared with that from the rumen of sheep. Another contributing factor might have been the presence of lignin and tannins, which might have been responsible for the relatively low intake of the NDF from the HF diet (Molina-Alcaide *et al.*, 1997), although such intake was not measured in the current study. The higher NDF content of the HF diet might also indirectly have contributed to a reduction in intake by reducing the rate of passage involved. Sanon *et al.* (2007) also found that, as soon as the fibre content increased, the digestion of the feed was suppressed, resulting in its negative correlation with feed intake. The fact that low-quality roughage is normally unpalatable, fibrous and deficient in nutrients might result in a lower level of intake by ruminants (Church & Santos, 1981). Gall (1981) also found that sheep tended to consume more fibrous material than did goats, a fact which would serve to support the higher intake of NDF by sheep which was detected in the current study. The higher NDF intake from the HF diet of sheep compared with that obtained by goats from the same diet was due to increased DM intake. The NDF intake from the low-fibre (LF) diet did not significantly differ ($P > 0.05$) between the two species examined in the current study.

Intake and digestibility are not optimal when forages contain a low amount of protein and a high amount of fibre, with it being reported that animals consuming such diets fail to meet their optimum growth requirements (Mekasha *et al.*, 2002). Though Ferrell (1999) found no differences in the NDF consumed by lambs, Reid *et al.* (1990) found increased NDF intakes for those goats and sheep which were fed diets containing between 41% and 73% NDF. The basis for such inconsistencies has not yet been elucidated.

Between species, sheep and goats were not found to differ significantly ($P > 0.05$) in terms of their ME intake. Such results are supported by the findings of Lu *et al.* (1990), who found that energy intake appeared to be the dominant factor influencing DM intake. The researchers concerned found that goats which were fed diets containing high energy (HE), but little protein, had lower energy intakes than when they were fed on a higher protein diet. Whereas CP might be expected to influence DM intake, the CP contents of the diets which were fed to the animals in the current study did not differ appreciably, so that differences in DM intake were not anticipated. Kyriazakis and Oldham (1993) found that the intake of feed increased for sheep which were fed a diet containing a higher CP level. As the amount of CP which is consumed influences DM intake and those diets which were used in the current study diets did not differ in terms of CP content, DM intake differences should not have been expected from the study.

The HF diet did not result in a significant ($P > 0.05$) difference for nitrogen intake when such intake was compared with that from the LF diet which was fed to the goats. Although the LF diet tended to increase the nitrogen intake of sheep, the difference which was detected was not found to be

significant ($P > 0.05$). No significant ($P > 0.05$) differences were found in the ME intake of those goats and sheep which consumed the LF diet.

Animals with a high potential growth rate normally require more energy for maintenance, with, in general, high-producing animals performing better when they were provided with high-quality diets and a nutritional environment in which the amount of stress was limited. The consumption of low-quality diets relative to the animal's body weight has been shown to be higher for low-producing animals than for high producers. As soon as forage quality increases, the intake of feed also tends to increase, with more energy being used by the more highly productive animals (Goetsch, 1998).

Although the sheep which were included in the current study showed no significant ($P < 0.05$) differences in energy intake, a significantly ($P > 0.05$) higher NDF intake from the HF diet in comparison with that from the LF diet was recorded. Such a result was anticipated, given the higher levels of NDF in the HF diet, compared with those which were present in the LF diet. The NDF intake from the HF diet was also significantly ($P < 0.05$) higher for goats in comparison with their NDF intake from the LF diet. Sheep and goats have been found normally to digest more NDF from low-quality diets than they tend to do from high-quality diets (Sanon *et al.*, 2007). In the current study, only one significant ($P < 0.05$) difference in intake between species was observed, in terms of which the sheep were found to consume more NDF from the HF than did the goats. Those variables which were evaluated (Table 2.2) in the current study indicated that the goats and sheep used in the study did not differ in terms of their intake depending on whether they were fed the HF or LF diet.

Nutrient digestibility

The apparent digestibility of nutrients in sheep and goats fed the HF and LF diet is shown in Table 2.3. No significant ($P > 0.05$) differences in DM, CP, NDF and apparent ME digestibility were observed between the goats and sheep which were included in the study. Both the goats and sheep exhibited similar patterns in their ability to digest various nutrients which were present in forage. Although the NDF content was higher in the case of the HF diet, no significant ($P < 0.05$) differences were recorded for the levels of DM digestibility between goats and sheep compared to when they consumed the LF diet. Reid *et al.* (1990) and Ramirez and Ledezma-Torres (1997) also found no differences in DM digestibility between goats and sheep. Such results are supported by Jones *et al.* (1972) and Huston (1978), who found that digestibility coefficients were similar between goats and sheep.

Table 2.3 Effect of different quality diets on the apparent digestibility characteristics of the nutrients absorbed by Boer goats and Dohne Merino wethers. All values (except where otherwise indicated) are on a DM basis

	LF ¹ diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
DM ² digestibility %	72.25 ± 07.00	61.58 ± 11.67	59.49 ± 12.16	57.89 ± 6.07
Apparent CP digestibility %	60.85 ± 11.78	51.01 ± 14.53	40.23 ± 10.27	46.72 ± 8.20
Apparent NDF digestibility %	27.02 ± 10.85	27.34 ± 10.98	26.17 ± 10.87	27.991 ± 10.87

¹LF = low-fibre; HF = high-fibre. ²DM = dry matter; CP = crude protein; NDF = neutral detergent fibre. Data with common superscripts did not differ (P < 0.05). Standard error of mean is indicated as ±.

Table 2.4 Effect of different quality diets on nitrogen retention by Boer goat and Dohne Merino wethers. All values (except where indicated otherwise) are on a DM basis

	LF ¹ diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
N – retention ¹	-6.6 ^a ± 0.027	-3.7 ^b ± 0.004	-5.8 ^a ± 0.001	-3.7 ^{ab} ± 0.008

¹LF = low-fibre diet; HF = high-fibre diet. ²N = nitrogen. Data with common superscripts did not differ (P < 0.05). Standard error of mean is indicated as ±.

Both goats and sheep were in negative nitrogen balance. The sheep showed significantly higher (P < 0.05) nitrogen retention compared with that of goats when they were both fed an LF diet. Ferrell *et al.* (1999) found similar results, stating that the apparent digestibility of nitrogen tended to be lower in energy-supplemented diets compared with that which was found to be present in low-quality diets. In the current study, no significant differences in nitrogen retention were found between goats and sheep when they were both fed the HF diet. Such findings are in line with those of Doyle *et al.* (1984), who found no differences in nitrogen retention between those goats and sheep which were fed chopped hay (*Trifolium subterraneum*). Gihad (1976) also found that nitrogen losses were similar for goats and sheep when they were fed tropical natural grasses. Moreover, Ramirez and Ledezma-Torres (1997) found that those goats which were fed three different diets retained the same amount of nitrogen from the different diets.

Table 2.5 The DE and metabolic energy values used to evaluate all treatments fed to Boer goats and Dohne Merino wethers. All values are on a DM basis

	LF ¹ diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
DE ² MJ/kg	11.26 ^{ac} ± 3.50	12.59 ^a ± 2.42	4.41 ^b ± 2.61	7.78 ^{bc} ± 1.37
ME MJ/kg	8.02 ^a ± 2.47	8.26 ^a ± 1.62	3.09 ^{bc} ± 1.83	5.44 ^{ac} ± 0.96

¹LF = low-energy diet; HF = high-fibre diet; ²DE = digestible energy; ME = Metabolisable energy. Data with common superscripts did not differ (P < 0.05). Standard error of mean is indicated as ±.

The higher energy digestibility for goats which were fed on an LF diet compared with those which were fed on an HF diet might be due to the higher energy content which was observed in the LF diet. Another contributory factor might be the great variation in the nature of data which was collected for evaluation. The nutritive requirements of goats are much higher than are those which are generally accepted for sheep (Huston, 1978). No significant differences in ME were detected between sheep and goats, though significant differences ($P < 0.05$) were observed within species in regard to a higher ME content. The extent of digestion of fibre is the ultimate determinant of digestibility, determining the amount of DE (Huston *et al.*, 1986), which can then be reasoned to have a direct effect on the outcome of this study's ME result. Treatments showed a significant ($P < 0.05$) difference in energy digestibility. The diets were formulated in such a way as to provide more energy in the LF diet than in the HF one, with the result being that the goats used then showing that they had accessed a higher ME content (Table 2.5) from the LF diet than from the HF diet.

Conclusion

In the 6×6 Latin square trial, no differences were found between the two species in regards to the intake of the HF and LF diets. The sheep and goats tended to perform more weakly in respect of nitrogen intake when they were fed the LF diet, though they digested the LF diet better. Accordingly, it is necessary to use the right amount of metabolic energy to ensure that protein is not wastefully used as an energy source. Sheep and goats do not differ in terms of intake and digestibility characteristics when they are fed LF or HF diets, although strong preferences occur within species regarding the digestibility of the NDF variable.

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CHAPTER 3

Rumen Degradation (*in sacco*) of Low- and High-Fibre Diets, and of Sunflower and Soybean Meal Oilcake in Dohne Merino Sheep and Boer Goats

Abstract

Six Dohne Merino sheep and six Boer goat wethers were used in two trials to determine the *in sacco* dry matter (DM) and crude protein (CP) degradability of (a) two complete diets and (b) two oilcake protein sources. Feedstuffs used consisted of a low-fibre (LF) diet, a high-fibre (HF) diet, soybean meal (SBM) oilcake and sunflower meal (SFM) oilcake. All the animals which were used in the study were fitted with rumen cannulae and received the same basal diet during the plant first and second trial. Samples of the respective substrates were incubated in the rumen in Dacron bags, which were removed at intervals of 0h, 3h, 9h, 12h, 24h, 36h, 48h, 72h and 96h for both the LF and HF diets. For the oilcake substrates, bags were removed at 0h, 2h, 4h, 8h, 12h, 16h, 24h, 36h and 48h. The disappearance of DM and CP was determined, with such disappearance being used to estimate the *in sacco* DM and CP degradability parameters. No significant differences ($P > 0.05$) were observed between the sheep and goats in terms of the soluble fraction of DM and CP for either the SBM or SFM. However, the sheep showed significantly ($P < 0.05$) higher values for the potential degradable fraction (b) of DM for the SFM in comparison with those values which were obtained for the goats. The effective degradable CP content of SBM was found to be higher with goats than it was with sheep, with the difference concerned being found to be significant ($P < 0.05$). Within species, significant ($P < 0.05$) differences in terms of degradability were observed between SBM and SFM. No significant differences were observed between sheep and goats for the soluble fraction of DM contained in either the LF or HF diet. In addition, no significant difference ($P > 0.05$) was observed within species in terms of either the LF or HF diet. However, both the sheep and goats used in the study were found to degrade the soluble fraction of CP content of the HF diet to a significant degree ($P < 0.05$), which was more effective than was the degradation of such a fraction in the case of the LF diet.

Key words: cannulae; Dacron; *in sacco*; soluble

Introduction

The traditional method of evaluating feed protein for ruminant animals is in terms of its crude protein (CP) content. In most parts of the world, new protein systems have been introduced to substitute for the digestible CP system. The new protein system makes use of the *in situ* nylon bag technique, which has become a widely used method for estimating ruminal degradation kinetics (Ilghami *et al.*, 2008). Such a technique allows for digestion to be studied within the rumen itself, thus reducing the need for ruminal simulation (Vanzant *et al.*, 1998).

Protein and fibre are two important nutritional components of the ruminant diet. Determination of the rate of digestion of protein and fibre is important for evaluating and comparing the composition of

different diets which are fed to sheep and goats. Within a production system or feed source, predicting growth potential is just as important as, as well as easier to, predicting the limitations in the nutrient and energy supply of sheep and goats, when the digestive capacity of the animals concerned is known (Lindberg & Gonda, 1997).

The performance of an animal can be negatively affected by a relatively long rumen digestion period for protein, which lessens the utilisation in the intestine of the available nutrient source (Lindberg & Gonda, 1997). Although the growth of goats and sheep is affected by rumen retention times, Ruiz *et al.* (2004) found that, in both species, the ruminal degradation profiles and fractional passage rates were similar for both diets. Reid *et al.* (1990), however, found that goats tended to digest dry matter (DM) and neutral detergent fibre (NDF) significantly better than did sheep, due to the higher turnover times, which were observed for the digestion of NDF and DM, compared with that for sheep. A close relationship has been found to exist between the amount of time that the feed spends in the rumen and the digestibility of the NDF (Fernandez *et al.*, 2003). Such a parameter may be used as an indication of which protein supplements positively affect the NDF of the total amount of feed consumed.

For optimal performance to be achieved during periods of high nutritional requirement, a diet with a high nutrient density is required, which might prove to be costly. Such a problem might partially be alleviated by the utilisation of mixed rations, which are likely to reduce both the levels of most concentrates in the feed and the quantities of the feed that is consumed. Improved productivity of sheep and goats can be achieved when a consistent supply of nutrient content is selected by both species (Fernandez *et al.*, 2003).

For a number of years, such plant protein sources as soybean meal (SBM) have been used in animal feed. Despite the utilisation of SBM having been sufficiently applied in nutritional research and feeding systems (Titi *et al.*, 2003), in some parts of the world SBM prices are high, with the related productivity being erratic. Consequently, alternative protein sources should be sought as an alternative plant feed source for livestock. As a result of the increased production of sunflower products, sunflower meal (SFM) has become a quality by-product which can be utilised for ruminant feeds (Schingoethe *et al.*, 1977). Similarly to SBM, SFM is a high protein supplement. However, SFM is known to degrade extensively in the rumen (Titi *et al.*, 2003). Even though SFM is being increasingly incorporated into ruminant feeds, limited research has been conducted into the utilisation of such a foodstuff by ruminants (Villamide & San Juan, 1998).

Considerable variation exists between sheep and goats in terms of their effective utilisation of protein. Such variation requires that research be directed towards the evaluation of different protein sources to determine the extent of their degradability by such ruminants. Though oilcake generally has a high protein content, the use of such oilcake in ruminant feed is often limited, due to the relatively high rate of rumen degradability. The aim of the current study was to determine whether the utilisation of SBM and SFM oilcake and two roughage-based diets differed between goats and sheep in terms of degradability parameters.

Materials and Methods

Animals and conditions

The *in sacco* technique (Ørskov & McDonald, 1979) was used in each of the six Dohne Merino sheep and Boer goat wethers which were fitted with rumen cannulae. The degradation of protein in rumen was evaluated by means of measuring the levels of utilisation of each diet by both species concerned. The animals, which were housed individually in 1 × 2 m metabolism crates, had *ad libitum* access to a basal diet consisting of 306 g/kg ground maize meal, 102 g/kg ground wheat, 152 g/kg chopped lucerne, 356 g/kg chopped oat hay, 50 g/kg cottonseed meal (CSM) oilcake, 32 g/kg Mutton Gainer 125 and water. The chemical composition of diets and protein used in the trial for the determination of *in sacco* degradation is presented in Table 3.1. Nylon bags (5 × 18 cm), constructed of polyamide (Polyman, Switzerland) with an estimated average pore size of 41 µm was used. The bags were oven-dried at 60 °C for 24h, and then cooled in a desiccator and weighed. Samples of SFM and SBM oilcake, and low-fibre (LF) and high-fibre (HF) feed were then ground through a 2-mm screen in a Wiley mill. A sub sample of each feedstuff was then taken for DM determination. Eight grams DM of each of the milled samples was weighed into the bags (used for analysis) concerned. All samples were sieved to remove fine particles smaller than 124 µ. The feed residue was used both for the chemical analysis, as well as for the *in sacco* trial.

Table 3.1 The chemical composition of diets and protein sources used in the trial. All values are expressed on a DM basis

Item	HF (g/kg)	LF (g/kg)	SBM (g/kg)	SFM (g/kg)
DM	860	820	894	907
CP	122	133	581	388
NDF	393	248	140	328
Ash	71	69	80	94

DM = dry matter; HF = high-fibre; LF = low-fibre; SBM = soybean meal; SFM = sunflower meal

Bags were closed with a nylon string and were incubated in the rumen for 0h, 3h, 9h, 12h, 24h, 36h, 48h, 72h and 96h (in the case of the LF and HF diets) and 0h, 2h, 4h, 8h, 12h, 24h, 36h, and 48h (in the case of the SFM and SBM diets). The 0h bags were not incubated in the rumen, and represent the original mass value when all the incubated bags and the 0h bags were washed in the washing-machine. Since those incubation times which were longer than 24h were not expected to leave sufficient residue for all the chemical analyses, duplicate bags were prepared for the 48h, 72h and 96h incubation times.

Sampling

Each sealed bag was individually attached to a metal ring disk, which was attached to the cannula plug with a piece of nylon string. The free length between the plug of the cannula and the bag was 25 cm (Mehrez & Ørskov, 1977). All the bags were simultaneously inserted and submerged in the rumen, after which they were collected at the relevant time intervals. After the bags were removed from the rumen, they were placed into buckets of cold water, after which they were rinsed under running cold tap water to halt microbial activity. The bags were then washed in cold water in a twin-

tub washing-machine for ten minutes, using the gentle cycle. The water was drained off after five minutes of washing, after which the bags were washed in fresh water for an additional five minutes. The (0h) ruminal incubation bags containing feed samples were washed in the same way as were the other bags to determine the soluble fraction.

All the bags were then dried in a forced draught oven at 65 °C, as described by Nocek (1985) and Janicki and Stallings (1988). At the end of the drying period, bags were cooled in a desiccator and weighed in order to calculate the residual DM. Residues were then removed from the bags and stored for further analysis. The contents of the duplicate bags (48h, 72h and 96h) were combined for analysis. The DM degradation was estimated in terms of the equation suggested by Ørskov and McDonald (1979) ($p = a + b(1 - e^{-ct})$), with p = potential degradability at time t ; a = rapidly degradable fraction at time zero; b = slowly degradable fraction; c = fractional rate constant at which the fraction described by b will be degraded per h ; and t = time of incubation.

Since the ruminal retention time affects the extent of degradation, a fractional outflow rate of undegraded protein from the rumen (k_p) was taken into account, when the effective degradability (D_{eff}) was calculated as $D_{eff} = a + bc / (c + k_p)$. The selected value was $k_p = 0.02$.

Laboratory analysis

Samples from the incubated bags and the initial sample were analysed for DM, CP and NDF. The NDF content was determined by means of an ANKOM²²⁰ Fibre Analyzer (ANKOM Technologies, Fairport, NY). All the nitrogen (N) samples were analysed according to the combustion method (AOAC 990.03, Method, 2002) by means of a Leco FP-428 Nitrogen and Protein Analyser (Leco Corporation, 3000 Lakeview Avenue, St. Joseph, MI 49085-2396).

Statistical analysis

Data were analysed as a 6 × 6 factorial treatment arranged in a randomised block design, using individual animals as replicates. CP and DM disappearances were expressed as percentages of incubated samples. The non-linear parameters a , b and c , as well as the effective degradability (D_{eff}) values, were submitted to a one-way analysis of variance (ANOVA) with the aid of the Minitab and Tukey's multiple comparison test. Values were considered significant at $P < 0.05$.

Results and Discussion

In sacco DM disappearance

A summary of the *in sacco* DM disappearance parameters is presented in tables 3.2 and 3.3. No significant differences ($P > 0.05$) were observed between the sheep and goats in respect of the soluble fraction of the SBM and SFM. However, SFM showed a significantly ($P < 0.05$) lower soluble fraction (a) than did the SBM in sheep and goats. Such a finding was in keeping with Titi's (2003) report that SBM had a higher solubility than did SFM. At 2h and 48h incubation time, the DM disappearance of the SBM was significantly ($P < 0.05$) higher at 3% than it was for the SFM. However, no significant difference ($P > 0.05$) was observed between the sheep and goats for the

soluble fraction (a) in either the LF or the HF diets. In addition, no significant difference ($P > 0.05$) was observed within species for either such diet.

Table 3.2 *In sacco* DM disappearance parameters in Dohne Merino and Boer goat wethers for the HF and LF diets

		LF ¹ diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
Rapidly soluble fraction ² (a) (%)	DM ³	30.10 ± 2.9	27.70 ± 1.80	27.70 ± 1.60	27.60 ± 3.60
Fraction degradable over time (b) (%)	DM	52.30 ± 5.5	55.80 ± 3.00	53.00 ± 2.30	56.80 ± 1.20
Rate of degradation (c) (%/h)	DM	0.06 ± 0.11	0.06 ± 0.01	0.05 ± 0.01	0.05 ± 0.02

¹LF = low-fibre; HF = high-fibre; ²a = rapidly soluble fraction (%); b = fraction degradable over time (%); c = rate of degradation of b (% / h); ³DM = dry matter. Data with common superscripts did not differ ($P < 0.05$). Standard error of mean is indicated as ±.

Table 3.3 *In sacco* DM disappearance parameters in Dohne Merino and Boer goat wethers for the two vegetable protein sources

		SBM ¹ diet Goats	SBM diet Sheep	SFM diet Goats	SFM diet Sheep
Rapidly soluble fraction ¹ (a) (%)	DM ³	31.60 ^a ± 1.90	30 ^a ± 1.50	21.70 ^b ± 2.70	19.80 ^b ± 4.40
Fraction degradable over time (b) (%)	DM	64.70 ^a ± 3.10	69.3 ^a ± 1.50	55.70 ^b ± 2.40	65.80 ^a ± 7.20
Rate of degradation (c) (%/h)	DM	0.07 ^{bc} ± 0.01	0.06 ^b ± 0.01	0.10 ^{ac} ± 0.01	0.12 ^a ± 0.04

¹SBM = soybean meal; SFM = sunflower meal; ²a = rapidly soluble fraction (%); b = fraction degradable over time (%); c = rate of degradation of b (% / h); ³DM = dry matter. Data with common superscripts did not differ ($P < 0.05$). Standard error of mean is indicated as ±.

In the current study, the sheep showed significantly ($P < 0.05$) higher values for the potential degradable fraction (b) of SFM in comparison with the goats. The SFM was found to be 10% more degraded by the sheep than it was by the goats. Such results might be due to the higher rumen retention time of sheep in comparison with goats (Huston, 1978). No significant ($P > 0.05$) difference was observed between the sheep and goats for fraction (b) of the SBM. However, within species, the degradable fraction (b) of the SBM was significantly ($P < 0.05$) higher than was that for the SFM for goats. The goats were found to degrade the SBM 9% better than they did the SFM. Such results are in contrast with those which were reported by Irshaid *et al.* (2003), who found no differences for digestibility parameters between SFM and SBM in Awassi lambs. The time which is spent by feed in

the rumen affects its digestibility. Fernandez *et al.* (2003) found that SFM (56% of retention time) stayed in the rumen longer than did SBM (50% of retention time). Such times might have affected the degradation rate for SBM in goats during this study. Gall (1981) found that goats tend to digest protein slightly better than do sheep. Such superior digestion by goats might have caused the differences between sheep and goats which were detected on the degradable (b) parameter. As SBM tends to contain higher levels of CP than does SFM, it might also have influenced the digestibility of the feed concerned for the goats.

The sheep used in the current study were found to show a significantly ($P < 0.05$) higher potential degradable fraction (b) for the HF diet than did the goats. Such a finding might have been due to the longer rumen retention time in sheep than in goats, as indicated by Huston (1978) and Katoh *et al.* (1988). Retention time was, however, not determined in the study. Gall (1981) also found that sheep tended to consume fibrous diets better than did goats, which might also have influenced the difference observed between the HF and LF diets incubated in both the sheep and the goats. A comparative study into energy utilisation by sheep and goats consuming moderate- to low-quality diets also revealed that, even though sheep and goats tend to utilise energy similarly, goats often utilise nitrogenous compounds in such diets better than do sheep (Kronberg & Malechek., 1997). Within species, however, no significant ($P > 0.05$) difference was observed for fraction (b) in the current study.

In terms of the rate of degradation (c), no significant ($P > 0.05$) difference was observed between goats and sheep for the SBM and the SFM diets. However, within species, the rate of degradation (c) was significantly ($P < 0.05$) lower for the SBM diet than it was for the SFM diet in sheep. Although not significant ($P < 0.05$), a strong tendency towards the same pattern was witnessed in the performance of those goats which were evaluated. No significant ($P < 0.05$) difference was observed for the rate of degradation (c) of the LF and HF diets between and among the sheep and goats used in the study.

Table 3.4 Effective degradability of DM in the HF and LF diets, as well as in the vegetable protein sources, by Dohne Merino and Boer goat wethers

	LF¹ diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
D_{eff} ($k_p = 0.02$) ²	58.30 ± 1.90	58.10 ± 2.60	53.90 ± 3.00	55.30 ± 4.40
	SBM diet Goats	SBM diet Sheep	SFM diet Goats	SFM diet Sheep
D_{eff} ($k_p = 0.02$)	69.20 ^b ± 2.10	68.10 ^b ± 1.50	59.50 ^a ± 2.50	66.10 ^b ± 3.80

¹LF = low-fibre; HF = high-fibre; SBM = soybean meal; SFM = sunflower meal; ² D_{eff} = effective degradability (%). Data with common superscripts did not differ ($P < 0.05$). Standard error of mean is indicated as ±.

The effective degradability for DM disappearance parameters is summarised in Table 3.4. The sheep used in the study were found to degrade the SFM significantly ($P < 0.05$) more effectively than did the goats. In contrast to these findings, Reid *et al.* (1990) and Gihad and El-Bedawy (1980) reported that digestibility differences between goats and sheep were significantly in favour of goats. No significant difference ($P < 0.05$) was observed between goats and sheep in terms of the degradation of SBM. Within species, goats were found to degrade the SBM more effectively than they did the SFM. Such results are in accordance with those of Stake *et al.* (1973), who found that the effective degradability of SBM was higher than that of the SFM in calves. Observing the (a) and (b) values, it appears that, in both species, the SBM consistently showed more effective degradation when compared with the degradation of the SFM. However, the rate of degradation was found to be higher for the SFM than it was for the SBM, which might have been due to the greater digestibility of fibre in the SFM compared with that in the SBM, which was a phenomenon suggested by Fernandez *et al.* (2003). No significant ($P > 0.05$) differences were observed between sheep and goats, or within the goat or sheep species, for the effective degradability of either the HF or the LF diet.

In sacco NDF disappearance

The *in sacco* NDF disappearance parameters are summarised in Table 3.5. No significant ($P > 0.05$) difference was observed between goats and sheep for the soluble fraction of the HF or LF diets. Within species, no significant difference was observed between the soluble fraction for the HF and LF diets. Such a phenomenon was expected, as no difference was found in the DM content of either feed. Such a finding is also in contrast with the findings of the research which was undertaken by Ramirez and Ledezma-Torres (1997), who found that goats tended to have a lower NDF digestibility for HF diets than they did for LF diets. The (b) fraction was not significantly ($P < 0.05$) affected by species differences or within feeds. Significantly higher differences ($P < 0.05$) were observed for the rate of degradation (c) in the sheep compared with those goats which were fed the LF diet. The sheep showed a 50% higher rate of degradation compared with that of goats fed the LF diet. Such an observation contradicts the findings of Huston (1978) and Katoh *et al.* (1988), who found that those sheep which they studied tended to have longer rumen retention time than did the goats. In the current study, a longer rumen retention time showed itself in a shorter rate of degradation.

Table 3.5 *In sacco* NDF disappearance parameters in Dohne Merino and Boer goat wethers for the HF and LF diets incubated up to 96h

		LF ¹ diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
Rapidly soluble fraction ² (a) (%)	NDF ³	5.00 ± 0.00	5.00 ± 0.00	5.00 ± 0.00	5.00 ± 0.00
Fraction degradable over time (b) (%)	NDF	60.92 ± 3.89	58.80 ± 2.85	65.59 ± 1.76	64.75 ± 8.10
Rate of degradation (c) (%/h)	NDF	0.09 ^b ± 0.02	0.21 ^a ± 0.03	0.08 ^b ± 0.01	0.09 ^b ± 0.02

¹LF = low-fibre; HF = high-fibre; ²a = rapidly soluble fraction (%); b = fraction degradable over time (%); c = rate of degradation of b (%/h); ³NDF = neutral detergent nitrogen. Data with common superscripts did not differ (P < 0.05). Standard error of mean is indicated as ±.

The effective degradability of NDF disappearance parameters is summarised in Table 3.6. No significant (P > 0.05) difference was observed between species in terms of the rapidly soluble fraction (a) of both the HF and LF diets. In addition, no significant (P > 0.05) differences were observed between and within species for the fraction degradable over time (b). However, regarding the rate of degradation (c), the sheep were found to degrade the LF significantly (P < 0.05) more effectively than did the goats. Such findings are supported by those of Garcia *et al.* (1995), who found that the sheep used in their study tended to degrade NDF more efficiently than did the goats. Similar results were found for sheep in terms of the effective NDF degradability of the LF compared with that for goats. The sheep were found to degrade the LF significantly (P < 0.05) more effectively than did the goats. Gall (1981) also found that the sheep used in his study tended to consume fibrous diets better than did the goats. No significant difference for NDF degradability was found between sheep and goats fed on the HF diet.

Table 3.6 Effective degradability of NDF for the HF and LF diets as observed for Dohne Merino and Boer goat wethers

	LF ¹ diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
D _{eff} (kp = 0.02) ²	44.74 ^c ± 2.33	52.37 ^a ± 2.17	46.12 ^{bc} ± 2.61	50.06 ^b ± 3.28

¹LF = low-fibre; HF = high-fibre; ²D_{eff} = effective degradability (%). Data with common superscripts did not differ (P < 0.05). Standard error of mean is indicated as ±.

In sacco CP disappearance

The *in sacco* CP disappearance parameters are summarised in Tables 3.7 and 3.8. No significant (P > 0.05) difference between goats and sheep was found in terms of the (a) values for either the SFM or the SBM. However, within species, the (a) value for the SBM was significantly (P < 0.05) higher than was that for the SFM. A decrease in protein concentration was observed after 12h incubation for the SFM, which might have led to the lower a value of such a concentration. Such a finding could

have been due to the apparent protein being highly degradable, though the potential protein was low in digestibility (Griffiths, 2004). Such a finding could only be explained by means of the non-homogeneous or representative sample analysis which was performed on the CP. In the current study, the soluble fraction (a) for the SFM was significantly ($P < 0.05$) lower than was such a fraction for the SBM in sheep and goats. Kamalak *et al.* (2005) and Titi (2003), who found similar results, stated that they found that the rapidly soluble protein fraction (a) of the SBM was significantly higher than was that of the SFM. Such a finding was in contrast with the findings of Irshaid *et al.* (2003), who observed no differences in the (a) values between the SBM and the SFM which was fed to the lambs. The higher degradability which was found for the SBM in comparison with that which was found for the SFM in the current study could be explained by the high (75% to 80%) degradability of the SBM in the rumen (Broderick *et al.*, 1988; Promkot & Wanapat, 2003).

Table 3.7 *In sacco* CP disappearance parameters in Dohne Merino and Boer goat wethers for the HF and LF diets

		LF ¹ diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
Rapidly soluble fraction ² (a) (%)	CP ³	5.00 ± 0.00	5.00 ± 0.00	5.00 ± 0.00	5.00 ± 0.00
Fraction degradable over time (b) (%)	CP	56.47 ^a ± 0.79	55.74 ^a ± 1.75	68.45 ^b ± 1.20	67.40 ^b ± 1.90
Rate of degradation (c) (%/h)	CP	1.13 ± 1.06	0.87 ± 0.79	1.07 ± 0.84	0.93 ± 0.76

¹LF = low-fibre; HF = high-fibre; ²a = rapidly soluble fraction (%); b = fraction degradable over time (%); c = rate of degradation of b (%/h); ³CP = crude protein. Data with common superscripts did not differ ($P < 0.05$). Standard error of mean is indicated as ±.

Table 3.8 *In sacco* CP disappearance parameters in Dohne Merino and Boer goat wethers for the two vegetable protein sources

		SBM ¹ diet Goats	SBM diet Sheep	SFM diet Goats	SFM diet Sheep
Rapidly soluble fraction ² (a) (%)	CP ³	39.40 ^b ± 1.40	41.90 ^b ± 3.10	30.30 ^a ± 2.20	29.30 ^a ± 2.40
Fraction degradable over time (b) (%)	CP	61.90 ± 1.30	58.20 ± 2.90	63.80 ± 2.30	61.80 ± 5.60
Rate of degradation (c) (%/h)	CP	0.20 ± 0.0001	0.16 ± 0.0007	0.22 ± 0.004	0.19 ± 0.0003

¹SBM = soybean meal; SFM = sunflower meal; ²a = rapidly soluble fraction (%); b = fraction degradable over time (%); c = rate of degradation of b (% / h); ³CP = crude protein. Data with common superscripts did not differ ($P < 0.05$). Standard error of mean is indicated as ±.

No significant ($P > 0.05$) differences were found between sheep and goats in terms of the (a) value for either the LF or the HF diet. The sheep and goats degraded the rapidly soluble fraction (a) of the HF as effectively than they did the LF diet. No interspecies differences were anticipated, as Ammerman *et al.* (1972) found similar digestion patterns for nutrients between the sheep and goats when hay was their primary feed source.

In terms of the fraction degradable over time (b), no significant ($P > 0.05$) difference was observed between goats and sheep for either the SFM or the SBM. Within species, goats and sheep also did not show significant ($P > 0.05$) differences for the degradability of SBM or SFM over time. Similar results were found by Economides and Koumas (1999, as cited by Irshaid *et al.* (2003), in which they showed that SBM could be replaced by SFM in lamb growth trials. The two researchers found no differences in degradability over time. Such a finding was in contrast with the reports by Stake *et al.* (1973), who determined that SFM-fed calves tended to utilise SFM better than did SBM-fed calves, and who also found superior weight gain for SFM-fed calves.

No significant ($P > 0.05$) differences were observed in the fraction degradable over time (b) between goats or sheep in regards to either the LF or the HF diet. Within species, the sheep and goats were found to digest the LF significantly ($P < 0.05$) more effectively than they did the HF diet. Low-digestibility roughages are often deficient in essential microbial substrate, and therefore might have caused the weakened degradability of the HF diet for both species (Dixon & Stockdale, 1999). However, the fibre digestion was not inferior for the HF diet in comparison with the LF diet, as determined in Chapter 2. No significant ($P > 0.05$) differences were observed for the rate of degradation (c) between goats and sheep for the LF and HF diets, as well as for the two vegetable protein sources.

The effective degradability of CP disappearance parameters is summarised in Table 3.9. When digestibility coefficients of different fractions of protein were analysed, significant differences were found. The goats were found to effectively degrade the SBM to a greater extent than did the sheep, with such a difference being found to be significant ($P < 0.05$). Such a result accords with the reports of Kronberg and Malechek (1997), who stated that goats tend to utilise nitrogenous compounds better than do sheep. Within species, the sheep effectively degraded the SFM to a significantly ($P < 0.05$) greater extent than they did the SBM. Such results are similar to those of Fernandez *et al.* (2003), who stated that small ruminants tend to degrade the CP fraction of SFM more effectively than they do that which is found in SBM. Such degradation patterns might be due to the high degradability of SBM in the rumen, as previously mentioned. Schingoethe *et al.* (1976) also found that the solubility of SBM tends to be higher in the rumen. The *in sacco* CP degradation kinetics (a, b and c) and effective protein degradability of SBM and SFM which were determined in the current study were found to be considerably lower than were those obtained by Kamalak *et al.* (2005). Protein source, pore size of the nylon bag and milling screen size or fistulated animals used in the experiment could have caused the differences between the two experiments.

Table 3.9 Effective degradability of CP for the HF and LF diets, as well as for the vegetable protein sources, as observed for Dohne Merino and Boer goat wethers

	LF ¹ diet Goats	LF diet Sheep	HF diet Goats	HF diet Sheep
D _{eff} (kp = 0.02) ²	61.36 ^a ± 0.82	60.42 ^a ± 1.90	58.62 ^{ab} ± 2.13	53.78 ^b ± 2.94
	SBM diet Goats	SBM diet Sheep	SFM diet Goats	SFM diet Sheep
D _{eff} (kp = 0.02)	80.4 ^a ± 1.40	75.7 ^b ± 2.10	80.20 ^a ± 2.40	82.6 ^a ± 1.50

¹LF = low-fibre; HF = high-fibre; SBM = soybean meal; SFM = sunflower meal; ²D_{eff} = effective degradability (%). Data with common superscripts did not differ (P < 0.05). Standard error of mean is indicated as ±.

No significant (P > 0.05) difference was observed between the goats and sheep used for the study in regards to the effective degradability of CP in the LF and HF diets. Within species, the sheep showed significantly (P < 0.05) superior effective degradability of the LF diet compared with that which was obtained for the HF diet. Although sheep and goats are both selective browsers, sheep are reported to perform better on high-energy diets than do goats (Sheridan *et al.*, 2003). In the current study, an observation was made that sheep tended to consume more water during the trial period than did goats. Thus, the low digestibility of HF by sheep might partly be due to the higher water consumption, which might have promoted faster rumen washout, and hence a faster passage through the system of the animals concerned. The relatively high consumption of water might have prevented contact between the HF and bacteria, which might have reduced the digestion thereof (Ammerman *et al.*, 1972). In the current study, no significant (P > 0.05) difference was observed between goats and sheep for the effective degradability of CP contained in the SBM and SFM diets. Such a finding was in accordance with Erasmus *et al.* (1994), who found that the SFM and SBM diets did not differ regarding the disappearance of CP in lactating Holstein cows.

Conclusion

Results from the study described in the current chapter showed that the protein supplements did not differ in relation to the digestibility parameters between sheep and goats. SFM oilcake was effectively degraded at 814 g/kg, comparing well with SBM oilcake (781 g/kg) for both species. The two protein sources that were used in the current experiment also provided energy and could be combined with undegraded dietary protein (UDP) to enhance the growth potential for both sheep and goats. The sheep used in the study were also found to degrade the protein content of the LF diet more effectively than did the goats, which is likely to make the LF diet more applicable for sheep in feedlot conditions. In brief, with sufficient supply of the right nutrients, optimisation of low-quality feeds can be increased for both species.

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CHAPTER 4

***In vitro* Dry Matter Degradation of Two Plant Protein Sources in Dohne Merino Sheep and Boer Goats**

Abstract

The dry matter (DM) degradability of two oilcake sources was determined *in vitro*. Soybean meal (SBM) and sunflower meal (SFM) oilcake was used as the protein feedstuffs. Samples of both types of oilcake were incubated in an ANKOM Daisy Incubator, being removed at 0h, 2h, 4h, 8h, 16h, 24h and 48h after incubation. SBM had a higher ($P < 0.05$) soluble DM content than did SFM and the DM fraction which was degradable over time was also higher in the case of SBM than it was in the case of SFM, as observed in the rumen liquor which was obtained from both sheep and goats. No significant difference was found in the rate of DM degradation between the two protein sources or between sheep and goats. Both the actual DM disappearance values at 8h and the (a), (b) and (c) values were used to compare the *in vitro* and *in sacco* method in terms of SFM and SBM. In this study, use of the *in vitro* method resulted in higher degradation values than did the *in sacco* method. The *in vitro* true digestibility parameters were also calculated for the SBM and SFM diets. No significant difference was observed between species for effective degradability.

Key words: dry matter; disappearance; *in vitro*.

Introduction

In developing countries, goats serve as a source of food and economic security, which makes them an important livestock commodity. In order to address the nutrient needs of ruminants, it is necessary to evaluate the amount of protein which is synthesised and degraded in the rumen and small intestine. Limited research has been undertaken into the protein requirements of goats compared with those of other livestock species. The Daisy method of ANKOM has been extensively used to evaluate the nutritional value of ruminant feeds. Such a method of feed analysis has been widely used and is one of the most accurate laboratory procedures, which might be applied to predict dry matter (DM) digestibility data for ruminants (Mabjeesh *et al.*, 2000). An adequate supply of nitrogen (N) enhances the productivity of ruminal micro-organisms, while supplementary nitrogen sources affect the utilisation of ligno-cellulosic feedstuffs by small ruminants (Alcaide *et al.*, 2003). Supplementation with nitrogen, therefore, has been found to stimulate fibre digestion *in vitro* (McAllan & Smith, 1983).

The feeding of protein which degrades too slowly in the rumen has been found generally to fail to supply the rumen with sufficient nitrogen for microbial production, due to the protein protection which resists ruminal degradation (Alcaide *et al.*, 2003). Such a finding emphasises the importance of ruminal degradation of protein, as such degradation directly affects growth. Although meal oilcake has been studied extensively in the case of non-ruminants, little research has been conducted into such a source of protein for ruminants. Sunflower meal (SFM) oilcake is marginally deficient in lysine, though

it contains approximately twice as much methionine as soybean meal (SBM) oilcake. As such, SFM is potentially an excellent source of protein for growing ruminants (Amos *et al.*, 1974). The first limiting amino acid (AA) in microbial protein for lambs is methionine, so that an increase in methionine should increase growth performance.

Consideration of the degradation of SFM and SBM is essential when comparisons are made between the two feeds. Protein with low degradation tends to be especially valuable to ruminants with high protein requirements, such as early-weaned lambs. Broderick *et al.* (1988) found that SBM at 79% degradability was more degradable in the rumen than was SFM, at 59% degradability. Although SFM is more degradable in the rumen than is SBM, the former is currently the second major plant protein, which is included to the amount of 248 884 tons in South African commercial diets (Briedenhann, 2009). Plant protein oilcake meals have been more extensively studied in the case of non-ruminants than they have in the case of ruminants, requiring that research be directed towards the evaluation of such protein sources in the case of the latter (Amos *et al.*, 1974). Shirley's (1986) study of steers, found that, in terms of its nutritional value, SFM performed equivalently to SBM in terms of animal performance. The use of SBM as a protein source tends currently to be decreasing, due to the increasing use of SFM as a by-product in feed formulations (Irshaid *et al.*, 2003; Briedenhann, 2009).

Since the latest feeding systems tend to emphasise the quantification of ruminal protein degradation, the degradation of feed proteins must be accurately assessed. The extent to which plant protein sources are degraded in the rumen influences the degree of supply and absorption of protein in the small intestine. Predicting the amount both of dietary protein reaching the small intestinal tract and of the synthesis of microbial protein from digested protein is the goal of many protein systems (Garrett *et al.*, 1987). Garrett *et al.* (1987) conducted a comparative study of sheep and goats to determine the *in vitro* rumen digestibility of SBM or SFM oilcake when donor animals were fed the same basal diet. *In sacco*, the SFM showed a significantly ($P < 0.05$) lower soluble fraction than did the SBM in the case of both sheep and goats. The potential degradable DM fraction was found to be significantly ($P < 0.05$) higher for the SFM in the case of the sheep than it was in the case of the goats. However, within species, the DM fraction of SBM was found to be significantly ($P < 0.05$) higher than that of SFM in goats. The goats were found to degrade the SBM 9% better than they did the SFM. The aim of the current study, which was completed simultaneously with the *in sacco* study, was to verify those results which were obtained with the two types of oilcake in the *in sacco* study (Chapter 3). The results of the *in sacco* and *in vitro* studies were also compared in order to evaluate the affectivity of each method.

Materials and Methods

Donor animals and rumen fluid inoculum preparation

Simultaneously with the *in sacco* degradability trial, an *in vitro* degradability study was completed in order to verify the results obtained, as well as to allow for a comparison between the two methods concerned. A composite sample of rumen liquid from six sheep, as well as one from six goats, which were used in the *in sacco* trial, was also used in the *in vitro* trial. The animals concerned were housed individually in 1 × 2 m metabolism crates, in which they had *ad libitum* access to a basal diet

consisting of 306 g/kg ground maize meal, 102 g/kg ground wheat, 152 g/kg chopped lucerne, 356 g/kg chopped oat hay, 50 g/kg cottonseed meal oilcake, 34 g/kg Mutton Gainer 125 and water (Table 3.1 in Chapter 3). The study was carried out at the facilities of the Welgevallen Experimental Farm of Stellenbosch University, in the Western Cape, South Africa. The animals concerned were fed twice daily at 08:00 and 16:30. The sheep and goats were allowed to adapt to the diet for 14 days before rumen liquid was collected for the *in vitro* study.

Rumen liquid was used to incubate all the duplicated bags in the ANKOM Daisy Incubator (ANKOM Technologies Corp., Fairport, NY). The rumen liquor, which was taken from all six animals, was handled under strictly anaerobic conditions. The combined rumen liquor of six sheep, as well as that of six goats, was divided into two separate incubation vessels per species. A mixture of rumen liquor and buffer (Goering & Van Soest., 1970), together with added cysteine sulphide-reducing agent, were used during incubation. The bags were incubated in duplicate in an ANKOM Daisy Incubator (ANKOM Technologies Corp., Fairport, NY) at 39 °C.

Sampling

The SBM and SFM types of oilcake were evaluated in an *in vitro* degradability trial. The raw materials were chosen, based on the limited research which was done on them, and the degree of accessibility to such information which was available in South Africa at the time.

The SBM and SFM were milled through a 2-mm screen using a Scientec hammer mill (Scientec, RSA). All samples were sieved to remove those fine particles which were smaller than 124 μ . The feed residue was used for chemical analysis, as well as for the *in vitro* and the *in sacco* trial.

Dacron bags of from 5 cm to 10 cm in diameter (R510 bags, ANKOM Technologies Corp., Fairport, NY), with a pore size of 53 μ , were used for the *in vitro* trial. Following the drying of the bags in an oven for 48h at 60 °C, 2-g samples were weighed into each bag. All the bags were marked individually and weighed beforehand. An ANKOM Heat Sealer (ANKOM Technologies Corp., Fairport, NY) was used to seal the bags with a double heat seal.

The *in vitro* and *in sacco* trials were conducted simultaneously to enable a comparison to be made between both experiments. Only four incubation vessels were used in the Daisy Incubator, which led to a relatively low degree of freedom in the statistical analysis. Two runs were used to incubate all the bags intended to contain the sample for either the sheep or the goats.

The incubated bags were removed at intervals of 0h, 2h, 4h, 8h, 16h, 24h and 48h. After extraction from the Daisy Incubator all the bags were washed under running water, after which they were frozen. Upon analysis, the bags were allowed to thaw overnight, after which they were dried in a forced draught oven at 60 °C for 24h, and then weighed to determine the degree of DM loss. The DM degradation was estimated in terms of Ørskov and McDonald's (1979) equation ($p = a + b(1 - e^{-ct})$), where p = potential degradability at time t ; a = rapidly degradable fraction at time zero; b = slowly

degradable fraction; c = fractional rate constant at which the fraction described by b will be degraded per h; and t = time of incubation.

As ruminal retention time affects the extent of degradation, a fractional outflow rate of undegraded protein from the rumen (k_p) was taken into account when the effective degradability (D_{eff}) was calculated as $D_{eff} = a + bc / (c + k_p)$, where k_p was assigned as 0.02.

The percentage *in vitro* true digestibility (%IVTD) was also calculated as follows (ANKOM Technologies Corp., Fairport, NY):

$$\frac{100 - (W_3 - (W_1 \times C_1)) \times 100}{W_2}$$

Where: W_1 = bag tare weight;

W_2 = sample weight;

W_3 = final bag weight after *in vitro* and sequential ND treatment; and

C_1 = blank bag correction (final oven-dried weight/original blank bag weight).

Statistical analysis

Data were analysed as a 4×4 factorial treatment arrangement in a randomised block design, using individual incubation vessels as replicates. DM and IVTD disappearances were expressed as percentages of the incubated samples. The rapidly soluble fraction (a), the fraction degradable over time (b), the rate of degradation (c), as well as the effective degradability (D_{eff}) values, were submitted to a one-way analysis of variance (ANOVA) with the aid of Minitab and Tukey's multiple comparison test. Values were considered significant at $P < 0.05$.

Results and Discussion

The chemical composition of the raw materials used in the current study is presented in Table 4.1.

Table 4.1 The chemical composition of SBM and SFM used in the trial. All values are expressed on a DM basis

Item ¹	SBM ² (g/kg)	SFM (g/kg)
DM	894	907
CP	581	388
Fat	33	24
Fibre	48	162
NDF	140	328
Ash	80	94

¹DM = dry matter; CP = crude protein; NDF = neutral divergent fibre; ²SBM = soybean meal; SFM = sunflower meal

In vitro DM disappearance

Table 4.2 presents the summarised *in vitro* DM disappearance parameters which were determined in the current study. No significant ($P > 0.05$) difference was observed between the sheep and goats in terms of the soluble DM fraction (a) of either SBM or SFM. Such results were in contrast with those reported by Alcaide *et al.* (2003), who found that the fraction (a) of SFM was higher in the case of sheep than it was in the case of goats. In the *in sacco* trial, similar results were found, in terms of which the sheep were also found not to differ from the goats in terms of the soluble fraction (a) of the SBM, compared with that of the SFM. However, the SFM showed a significantly ($P < 0.05$) lower soluble DM fraction (a) within both species, which relates to the *in sacco* data reported in Chapter 3. Hoover (1986) found that changes in either the rumen environment or the microbial population might influence the rate at which $\text{NH}_3\text{-N}$ is taken up by microbes, thus affecting microbial production at a given ammonia concentration. Such a finding might have contributed to the high rate of degradability of the SBM in both species. SBM has been found to provide more nitrogen to microbes, as well as enhancing the degradability thereof, in comparison with SFM degradation, in the rumen of sheep and of goats. SFM has been found to contain more neutral detergent fibre (NDF), which can influence the natural degradability concerned. Soybean protein has also been found to provide AA's, which benefit productive cows in first (methionine), second (valine) and third (isoleucine) limiting order. In addition, SBM has been found to contain high levels of lysine (Nowak *et al.*, 2005), which is a rapidly degradable protein source. The protein of soybean is degraded at 70% to 80% in the rumen (Broderick *et al.*, 1988; Promkot & Wanapat, 2003), which limits its inclusion in diets for high-yielding ruminants. The disappearance of DM from those ANKOM bags which were incubated in the Daisy increased over time in the incubator. At 48h incubation time, the disappearance of SBM DM for sheep at 93.4% (± 1.44), and for goats at 92.9% (± 0.70), was significantly higher than it was for SFM at 66.7% (± 1.41), and 65.6% (± 0.70), respectively.

Table 4.2 *In vitro* DM disappearance parameters in Dohne Merino sheep and Boer goats for SBM and SFM

		SBM diet Goats	SBM diet Sheep	SFM diet Goats	SFM diet Goats
Rapidly soluble fraction ² (a) (%)	DM	28.59 ^a \pm 0.10	28.59 ^b \pm 0.10	20.84 ^b \pm 0.20	20.66 ^b \pm 0.10
Fraction degradable over time (b) (%)	DM	68.23 ^a \pm 0.42	68.00 ^b \pm 0.40	55.78 ^b \pm 1.10	55.28 ^b \pm 1.40
Rate of degradation (c) (%/h)	DM	0.47 \pm 0.07	0.47 \pm 0.13	0.42 \pm 0.20	0.47 \pm 0.09

¹SBM = soybean meal; SFM = sunflower meal; ²a = rapidly soluble fraction (%); b = fraction degradable over time (%); c = rate of degradation of b (%/h); ³DM = dry matter. Data with common superscripts did not differ ($P < 0.05$). Standard error of mean is indicated as \pm .

No significant ($P > 0.05$) difference was observed between the two species for the degradable fraction over time (b) for either SBM or SFM. However, SBM showed significantly ($P < 0.05$) higher degradable differences than did SFM in goats and sheep (Figure 4.1 and Figure 4.2). Similar results were found for goats *in sacco* (Table 3.3 in Chapter 3), though the sheep showed no difference in this

regard. Kamalak *et al.* (2005) also found that the degradability of the DM of SBM was significantly ($P < 0.05$) higher than was that for SFM in sheep. Such a finding was, however, in contrast with the reports of Irshaid *et al.* (2003), who found no differences for DM digestibility between the SFM and SBM in Awassi sheep. Such conflicting observations might have been due to the time that the feed spent in the rumen, as digestibility is directly affected by rumen retention time.

No significant ($P > 0.05$) difference was found to occur between sheep and goats in respect of the DM degradation rate (c) for either SBM or SFM. In contrast, Kamalak *et al.* (2005) and Stake *et al.* (1972) stated that the rate for SBM was found to be higher than it was for SFM in sheep. The *in sacco* trial showed contradictory results compared with the *in vitro* trial, as the degradation rate for SFM was found to be higher than for the SBM *in sacco*. Such an observation might be explained by the findings of Fernandez *et al.* (2003), who found that the retention time for SFM was longer in the rumen than it was for SBM.

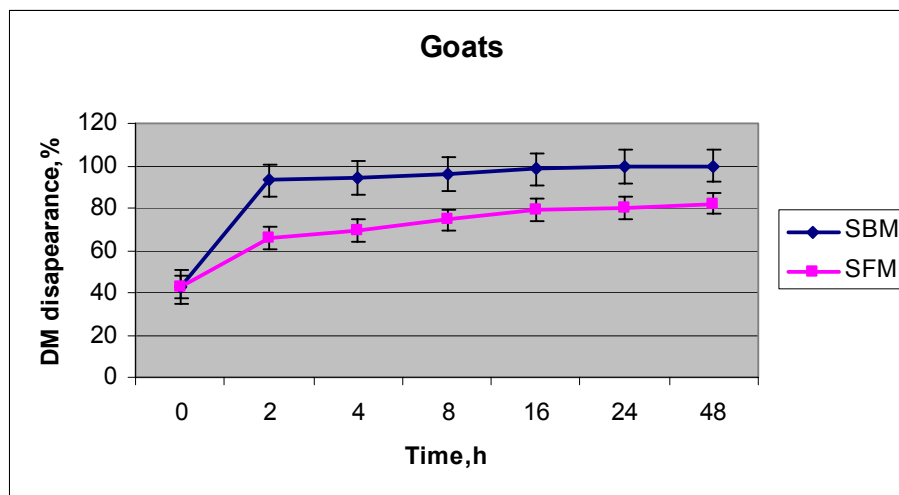


Figure 4.1 Percentage DM disappearance of SFM and SBM in goats.

Error bars represent the SEM concerned

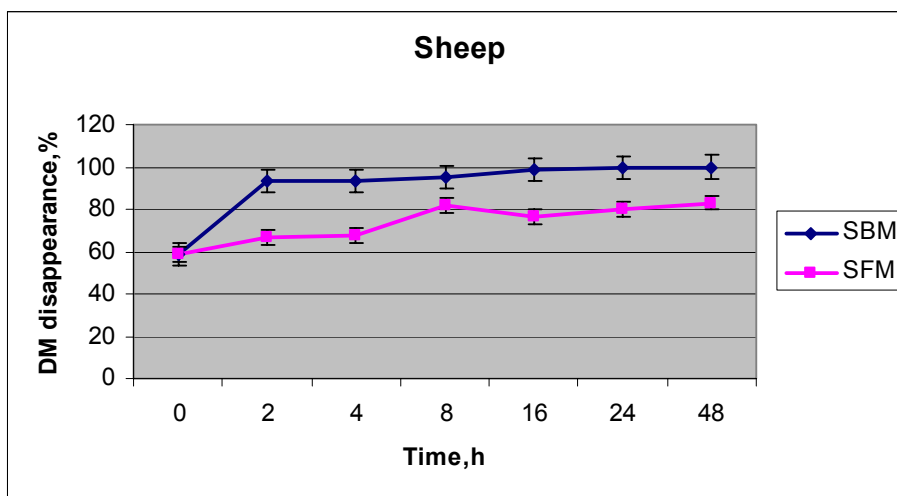


Figure 4.2 Percentage DM disappearance of SFM and SBM in sheep.

Error bars represent the SEM concerned

The effective degradability for DM disappearance parameters is summarised in Table 4.3. No significant ($P > 0.05$) difference was observed between species in respect of the effective degradability of DM for either the SBM or the SFM. In contrast, Garcia *et al.* (1995) found that goats showed faster feed degradation rates than did sheep. Within species, the effective degradability ($P < 0.05$) of SBM was shown to be significantly ($P < 0.05$) higher than that for SFM. Such a finding might be due to the lower DM and NDF digestibility of SFM, in comparison with that of SBM (Irshaid *et al.*, 2003). Similar results were observed in the *in sacco* study for both goats and sheep, in which SFM showed a significantly ($P < 0.05$) lower soluble fraction (a) and lower fraction degradable over time (b) than did SBM. In contrast, Fernandez *et al.* (2003) found that SFM had greater fibre digestibility than did SBM.

Table 4.3 Effective degradability of DM in SBM and SFM in Dohne Merino sheep and Boer goats

	SBM ¹ diet Goats	SBM diet Sheep	SFM diet Goats	SFM diet Sheep
D_{eff} (kp = 0.02) ²	96.80 ^a ± 0.41	96.57 ^a ± 0.46	74.69 ^b ± 1.41	75.92 ^b ± 1.41

¹SBM = soybean meal; SFM = sunflower meal; ² D_{eff} = effective degradability (%). Data with common superscripts did not differ ($P < 0.05$). Standard error of mean is indicated as ±.

Due to a lack of comparative data, the trial was extended by comparing the *in vitro* effective degradability values obtained in the current chapter with the *in sacco* effective degradability values obtained in the previous chapter (Table 3.4).

The actual DM disappearance values at 8h, as well as the (a), (b) or (c) values, were used to compare the methods in terms of both SFM and SBM. Due to the small sample size used in the *in vitro* trial and the high disappearance rate of the SBM, smaller amounts of residues were available, which might

have influenced the accuracy of the analysis in respect of the model in relation to the DM disappearance parameters. The *in sacco* method is assumed to be an accurate estimation of DM degradability and proof in the current study that the *in vitro* method overestimates degradation in most cases (Table 4.4). The DM disappearance values for all SBM samples were found to be higher *in vitro*. Griffiths (2004) and Broderick *et al.* (1988) also found higher DM values using the *in vitro* method in comparison with those obtained when using the *in sacco* method. The differences between the two methods might have been responsible for the variations in the results obtained. The composition of the microbial population, pH and the temperature in the rumen of the trial animals might have varied to the vessels of the Daisy Incubator (Griffiths, 2004). However, the effect of all such parameters was outside the scope of the study and was, therefore, not investigated. In contrast, Dewhurst *et al.* (1995) found an overestimation by the *in sacco* technique compared to the *in vitro* method. High fermentability was found for feed with soluble constituents in the *in sacco* method. Varel & Kreikemeier (1995) also stated that when using the *in vitro* method a slower rate and extent of digestion can occur when compared with the *in sacco* method. The pH value for the rumen vessels in the Daisy Incubator was amended to pH 6.8, though no correction was made for the *in sacco* trial. The two methods did not differ significantly ($P > 0.05$) in terms of the (a) and (c) variables (Table 4.5). However, in sheep, the b variable determined by means of the *in sacco* method resulted in overestimation, which was determined by means of the *in vitro* method. In the current study, the overestimation was only observed for the SFM, and not for the SBM, in terms of the b variable. No significant differences were observed for the goats used in the study.

Table 4.4 Actual DM disappearance of the *in sacco* and *in vitro* trial at 8h incubation

		SBM¹ diet Goats	SBM diet Sheep	SFM diet Goats	SFM diet Sheep
D _{eff} of DM ²	IS ³	58.97 ^a ± 1.24	55.33 ^a ± 1.74	54.03 ^a ± 1.41	64.74 ^a ± 1.69
	IV	96.05 ^b ± 0.46	94.85 ^b ± 1.37	74.36 ^b ± 1.52	81.83 ^b ± 7.71

¹SBM = soybean meal; SFM = sunflower meal; ²D_{eff} = effective degradability (%); DM = dry matter;

³IS = *in sacco*, IV = *in vitro*

Table 4.5 *In vitro* and *in sacco* DM disappearance parameters in Dohne Merino sheep or Boer goats for SBM and for SFM

		SBM ¹ diet Goats	SBM diet Sheep	SFM diet Goats	SFM diet Sheep
Rapidly soluble fraction ² (a) (%)	IS ³	31.63 ± 1.91	30.06 ± 1.55	21.77 ± 2.70	19.86 ± 4.42
	IV	28.59 ± 0.01	28.59 ± 0.10	20.84 ± 0.20	20.66 ± 0.10
Fraction degradable over time (b) (%)	IS	64.78 ± 3.18	69.39 ± 1.50	55.73 ± 2.40	65.85 ^a ± 7.24
	IV	68.23 ± 0.42	68.00 ± 0.40	55.78 ± 1.10	55.28 ^b ± 1.40
Rate of degradation (c) (%/h)	IS	0.07 ± 0.01	0.06 ± 0.05	0.15 ± 0.11	0.12 ± 0.04
	IV	0.47 ± 0.07	0.47 ± 0.13	0.42 ± 0.20	0.47 ± 0.09

¹SBM = soybean meal; SFM = sunflower meal; ²a = rapidly soluble fraction (%); b = fraction degradable over time (%); c = rate of degradation of b (% / h); ³IS = *in sacco*; IV = *in vitro*. Data with common superscripts did not differ (P < 0.05). Standard error of mean is indicated as ±.

In vitro true digestibility

The percentage IVTD parameters are summarised in Table 4.6. No significant (P > 0.05) difference was obtained between species for either SFM or SBM. Such findings correspond with those of Houston *et al.* (1986), who reported that the digestibility of both SFM and SBM diets was intermediate in sheep and goats, and did not differ from each other significantly (P > 0.05).

Table 4.6 IVTD of SBM and SFM in Dohne Merino sheep and Boer goats

Incubation (t) ²		SBM ¹ diet Goats	SBM diet Sheep	SFM diet Goats	SFM diet Sheep
2 h	DM ³	48.62 ^a ± 2.88	47.58 ^a ± 2.24	21.10 ^b ± 1.60	20.69 ^b ± 1.76
4 h	DM	48.33 ^a ± 0.49	47.69 ^a ± 0.72	22.50 ^b ± 0.68	19.33 ^b ± 0.87
8 h	DM	50.07 ^a ± 1.70	50.04 ^a ± 1.57	28.47 ^b ± 0.84	35.89 ^b ± 8.23
16 h	DM	52.86 ^a ± 1.51	53.40 ^a ± 1.14	34.27 ^b ± 5.87	30.68 ^b ± 1.46
24 h	DM	55.14 ^a ± 0.83	54.48 ^a ± 0.39	37.42 ^b ± 6.01	34.49 ^b ± 1.14
48 h	DM	54.17 ^a ± 1.34	53.80 ^a ± 1.41	36.35 ^b ± 35.19	35.19 ^b ± 3.84

¹SBM = soybean meal; SFM = sunflower meal; ²t = time; ³DM = dry matter. Data with common superscripts did not differ (P < 0.05). Standard error of mean is indicated as ±.

However, Larbi *et al.* (1997) suggested that sheep and goats differ in digestibility parameters. Houston *et al.* (1986) also found that goats tended to differ from sheep due to a faster turnover and shorter retention time of feed in the rumen. In the current study, the SBM was significantly (P < 0.05)

more degraded than was the SFM by both species studied. Kamalak *et al.* (2005) also found that the sheep tended to digest the SBM significantly ($P < 0.05$) better than they did the SFM. Griffiths (2004) stated that SBM is a rapidly degradable protein source compared with SFM, which might limit the inclusion of SBM in diets for high-yielding ruminants. True ruminal digestibilities of NDF, nitrogen and organic matter can increase rapidly with the inclusion of more SBM in the diet (Stokes *et al.*, 1988). Differences in terms of SBM digestion can occur between sheep and goats, according to Garcia *et al.*'s (1995) findings that goats had faster feed degradation rates than did sheep. Such results were proved by those *in vitro* digestibility parameters which were obtained by Alcaide *et al.* (2003), who found that goats tend to digest protein diets significantly better than do sheep. Garcia *et al.* (2003) also found *in vitro* differences between sheep and goats when the two species were fed olive cakes. However, Ammar *et al.* (2008) stated that they found no differences between sheep and goats in terms of *in vitro* digestibility when the two species were fed browse plant samples.

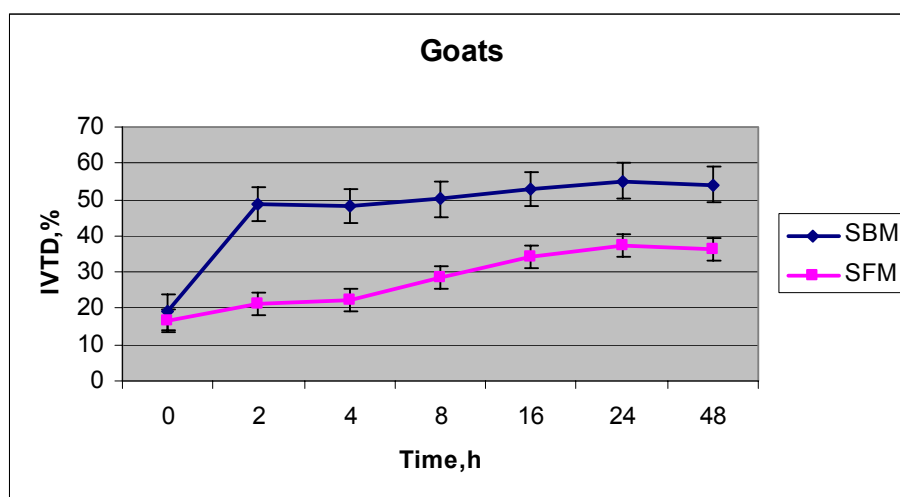


Figure 4.3 Percentage IVTD of SFM and SBM in goats.

Error bars represent the SEM concerned

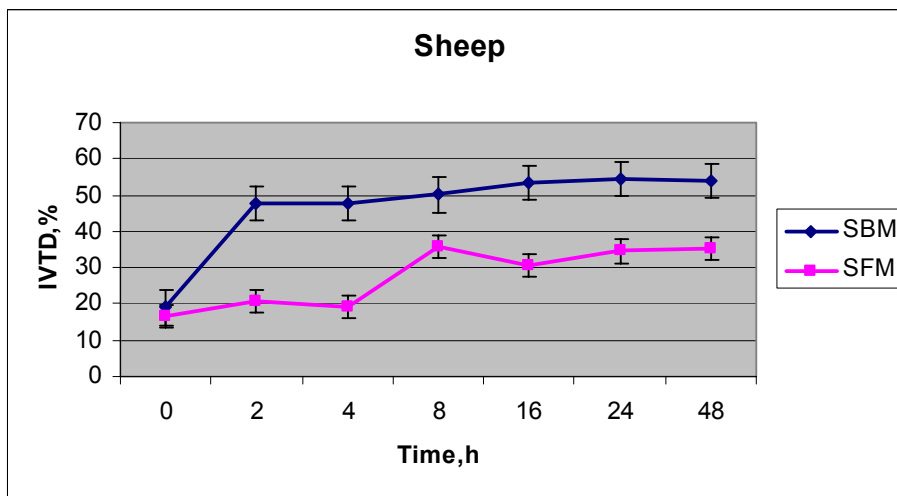


Figure 4.4 Percentage IVTD of SFM and SBM in sheep.

Error bars represent the SEM concerned

Conclusion

In the current study, DM degradation parameters were determined for commercially available plant protein sources used in goat and sheep nutrition in South Africa. The results clearly showed that significant differences occurred between protein sources in terms of DM disappearance and degradability parameters. Goats and sheep showed higher DM degradability for SBM compared with that for SFM. Those DM degradation parameters which were obtained using sheep and goats might prove useful in improving the accuracy of formulation of sheep and goat diets in South Africa. In the current study, the *in vitro* method overestimated degradation at 8h incubation. However, such a method might provide a cost-effective alternative to the more traditional *in sacco* method.

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CHAPTER 5

General Conclusion

The aim of the current study was to provide the industry with information regarding the differences between sheep and goats regarding the intake and digestible parameters of high-fibre (HF) and low-fibre (LF) diets. Following the evaluation described in the study, both similarities and differences in the degradable characteristics of sheep and goats in regards to soybean meal (SBM) and sunflower meal (SFM) oilcake was studied. Differences within the same species were also observed. The protein sources evaluated are both commonly used in South African high-production ruminant diets (dairy), though the feed dictionaries of popular dynamic models and programmes generally lack data regarding their use in small ruminants, such as sheep and goats.

Regarding the utilisation of LF or HF diets, no difference was found between goats or sheep in respect of nutrient digestibility, although differences were observed regarding the intake of the nutrients concerned. The sheep were found to consume more neutral detergent fibre (NDF) than did the goats. The higher NDF intake for sheep can be explained in respect of the results obtained by Isac *et al.* (1994) and Lu *et al.* (1990), who found an increased outflow rate from the rumen in goats compared with that in sheep. Goats, in contrast, showed a higher intake of crude protein (CP) than did sheep, with the former perhaps digesting the CP of the HF better than they did that of the NDF (Gihad & El-Bedawy, 1980; Reid *et al.*, 1990). In terms of the intake parameters analysed, no significant difference was observed within species for total digestible nutrients and nitrogen retention.

The effective degradability and disappearance of NDF with the LF diet showed better degradation in the case of the sheep than it did with the goats. No difference was observed in respect of the HF diet regarding degradability and disappearance parameters between species, during the *in sacco* trial. However, Reid *et al.* (1990) and Gihad and El-Bedawy (1980) showed that digestibility differences between goats and sheep were significantly in favour of the goats. The goats, in contrast, were found to digest the SBM more efficiently than did the sheep, due to the higher degradability of CP in the case of the SBM diet than in the case of the SFM diet. Within species, the sheep showed significant results for effective degradability of the CP contained in the SFM diet.

In terms of the effective degradability of the dry matter (DM) contained in the SFM, the *in sacco* results differed from the *in vitro* results observed. The sheep studied showed higher effective DM digestion *in sacco* of the SFM than did the goats. During the *in vitro* trial, no significant difference was found to have occurred between the sheep and the goats in terms of DM digestibility in respect of both the HF and LF diets. When observing the (a) and (b) values, during the *in sacco* trial, the SBM showed higher degradation values. However, the rate of degradation ([c] value) was found to be higher for SFM than it was for SBM in both species studied. The *in vitro* method indicated similar results, in terms of which it was observed that the SBM was effectively more degradable than was the SFM in the case of both the sheep and the goats. The extent of actual DM disappearance after 8h incubation

was used to compare the methods in the case of both SFM and SBM. After comparison, the two sets of data were analysed to highlight the differences which were found between the two diets in both experiments. The 8h DM disappearance values for the SBM, as well as for the SFM, were higher *in vitro*, which indicated, in the case of the current study, that the *in vitro* method overestimated the degradation which occurred in most cases. In keeping with such a finding, Griffiths (2004) and Broderick *et al.* (1988) also found higher DMD values using the *in vitro* method than that did when using the *in sacco* method. The lower effective degradability results which were found with use of the *in sacco* method might be related to the lower incubation values at 8h, which were found in comparison with use of the *in vitro* method. More research is necessary to explain such an observation. In the case of additional investigation confirming such a phenomenon, use of such a method might provide a cost-effective alternative to use of the more traditional *in sacco* method.

The *in vitro* true digestibility parameters were evaluated between sheep and goats in respect of both SFM and SBM. Though no significant difference was observed between species, goats and sheep showed higher digestibility for the SBM diet than they did for the SFM diet. The *in vitro* experiment clearly showed that digestion differences between SBM and SFM exist. The DMD parameter for SBM in the *in vitro* (97.74%) trial correlates with that which was obtained in the *in sacco* (99.87%) trial results.

On completion of the evaluation, the conclusion can be drawn that sheep and goats do not differ in their digestion parameters when they are compared in terms of different roughages or protein substances. However, within species, differences do occur. SBM and SFM should be protected to minimise rumen degradability in sheep (SBM at 97.74% and SFM at 80.98%) and goats (SBM at 97.68% and SFM at 80.63%), thereby increasing the rumen-undegradable protein (RUP) content of such protein sources.

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