Some Animal and Feed Factors Affecting Feed Intake, Behaviour and Performance of Small Ruminants

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Abstract

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The overall objective of this thesis was to assess the effect of some animal and feed factors on feed intake, behaviour and performance of small ruminants. The experiments were carried out at the Goat and Rabbit Research Centre in Northern Vietnam.

The effects of two physical forms of whole sugar cane (WSC) and four different levels of WSC offered with or without concentrate on feed intake, selection and eating behaviour of weaned goat kids and lambs were studied. Both kids and lambs fed with WSC chopped in slices (1-3 cm) had higher daily dry matter intake (DMI) than those fed WSC chopped into 20 cm lengths (208 g versus 173 g/day) and eating time was reduced as chopping length of the WSC decreased. Kids had higher DMI of WSC than lambs (214 g versus 166 g/day) and spent more time eating. The DMI of lambs was highest when WSC was offered at 6% of body weight, while DMI of kids was not significantly changed as the amount of WSC offered was increased. Adding concentrate as a supplement had no effect on the DMI of WSC, only on total DMI.

Of the presentation methods tested hanging the foliage from the wall of the pen or tying in the trough resulted in higher intake, while chopping or stripping the leaves gave lower intakes. The highest DMI (637 g/day) was obtained with Jackfruit (JF, *Artocarpus heterophyllus*), a moderate DMI (247 g/day) of Flemingia (FM, *Flemingia macrophylla*) and lowest intake (138 g/day) with Acacia (AC, *Acacia mangium*). The DMI of goats fed mixtures of JF+FM or JF+FM+AC was higher than of those fed mixtures of JF+AC or FM+AC. The DMI of kids fed mixtures of JF+FM or FM+AC was higher with the hanging than with the tying method, while this was the opposite case for the mixtures of JF+AC or JF+FM+AC.

Adding bamboo charcoal to the diet increased dry matter (DM), organic matter (OM) and crude protein (CP) digestibility and nitrogen retention. The highest DM, OM, CP digestibility and N retention were obtained in goats fed 0.5 or 1.0 g charcoal/kg body weight /day. The goats given the diet with bamboo charcoal grew faster than those given the diet without bamboo charcoal. The highest total DMI was obtained by goats fed wilted Acacia, significantly different from fresh and dried Acacia. However, the weight gain of the goats was similar among the three processing methods of Acacia.

Keeping goat kids and lambs in five different group sizes of 1 to 5 animals per pen showed that the kids fed the diet consisting of JF had a higher total DMI than lambs fed the same diet, while there was no difference in total DMI between kids and lambs fed a diet consisting of a mixture of foliages from JF+AC. The feed intake linearly increased with increasing number of animals in the pens, but more aggressive behaviour was recorded in pens with higher numbers of animals. The weight gain was higher for the lambs compared to the kids, but was similar for animals in the group size of 1 or 5 animals

Key words: Goats, Sheep, *Saccharum officinarum*, *Artocarpus heterophyllus*, *Flemingia macrophylla*, *Acacia mangium*, bamboo charcoal, processing methods, presentation methods, intake, behaviour, digestibility, nitrogen balance, growth.

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For
My parents,
My brother, Do Thanh Son
My husband, Nguyen Duy Ly
My daughter, Nguyen Thi Thu Trang

Contents

Appendix

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals:

I. Van, D.T.T., Ledin, I. & Mui, N.T. 2002. Feed intake and behaviour of kids and lambs fed sugar cane as the sole roughage with or without concentrate. Animal Feed Science and Technology 100 (1-2), 79-91

II. Van, D.T.T., Mui, N.T. & Ledin, I. 2005. Tropical foliages: Effect of presentation method and species on intake by goats Animal Feed Science and Technology 118, 1-17

III. Van, D.T.T., Mui, N.T. & Ledin, I. 2006. Effect of method of processing *Acacia mangium* and inclusion of bamboo charcoal in the diet on performance of growing goats. Animal Feed Science and Technology. (In press)

IV. Van, D.T.T., Mui, N.T. & Ledin, I. 2006. Effect of group size on feed intake, aggressive behaviour and growth rate in goat kids and lambs. (Submitted)

Papers **I, II** and **III** are included with the kind permission of the journal concerned.

List of abbreviations

AC	*Acacia mangium*
ADF	Acid detergent fiber
BW	Body weight
CP	Crude protein
CT	Condensed tannins
DM	Dry matter
DMI	Dry matter intake
FCR	Feed conversion ratio
FEC	Faecal egg count
FM	*Flemingia marcrophylla*
JF	*Artocarpus heterophyllus* (Jackfruit)
ME	Metabolizable energy
N	Nitrogen
NDF	Neutral detergent fiber
OM	Organic matter
PEG	Polyethylene glycol
$W^{0.75}$	Metabolic body weight
WSC	Whole sugar cane

Introduction

Small ruminants occupy an important economic and ecological niche in agricultural systems throughout the developing countries (Devendra, 2005). They provide animal protein (meat and milk), fibre and skins, draught power in the highlands, food security and a stable household income, and they have a whole range of advantages over large ruminants in terms of adaptation to and interaction with the environment, size and integration of the production systems in the farming systems and products.

Small ruminant production has been established in extensive management systems for many years in Vietnam. Only since 1992, however, has the Vietnamese government started to pay more attention to small ruminants. Due to the ongoing problems with Avian flu, when millions of poultry were killed and poultry keeping has been restricted, small ruminants have attracted more interest both from the government and the farmers and keeping goats and sheep seems to give more benefits and be safer than poultry production. The number of goats has increased from 525,000 head in 2000 to 1,001,000 head in 2004, with an annual growth rate of 47.2% and is estimated to be 10 millions in 2010. The number of sheep has increased from 4,500 head in 2000 to 21,200 head in 2004, with an annual growth rate of 116.5% (Binh & Lin, 2005).

There are two local goat breeds in Vietnam, Bachthao and Co, and both have been present for more than one hundred years. Some exotic breeds have been imported to diversify the goat gene resources and to improve the productivity of the local goat breeds. Three dual purpose (meat-milk) goat breeds (Barbari, Beetal and Jumnapari) were imported from India in 1994 and three high yielding breeds (Boer, Alpine and Saanen) from the US in 2002. There is only one local breed of sheep, the Phan Rang breed, named after the province where they have been kept, and originally imported from Mongolia and China.

The two main systems for management of small ruminants in Vietnam are the extensive management system, common for local animals, and the intensive management system using cut and carry feeding, which is common for imported and crossbred animals with higher yields. Feeding systems for small ruminants in Vietnam are mostly based on locally available feed resources (Mui & Preston, 2005). Many studies have been conducted to identify biomass yield of forages and multipurpose trees (Mui, 1994; Mui *et al.*, 1997; 2000; Man *et al.*, 1995; Tien *et al.*, 1997) and to make greater use of locally available feed resources for small ruminants (Binh & Preston, 1995; Mui *et al.*, 2000; Van & Ledin, 2002).

However, some studies (An *et al.*, 1992; Man *et al.*, 1995) have shown that the feed intake of some roughage resources is low, probably due to the high fibre content and high content of anti-nutritional factors such as tannins (Ben Salem *et al.*, 2005). The feed intake of these roughage resources has been reported to be especially low for imported goat breeds and crosses. Therefore, there is a need to find ways to improve the feed intake of locally available feed resources to satisfy the high nutrient requirements of high yielding animals in cut and carry feeding systems.

Objectives

The general objective of the studies was to find better methods of feeding sugar cane and some protein-rich foliage species to get the highest feed intake and the best performance in small ruminants.

The specific objectives were:

- To assess the effect of animal factors such as animal species (sheep and goats) and group size (single and group pens) on feed intake, behaviour and growth rate.
- To test the effect of some feed factors such as
    - processing method of sugar cane and Acacia foliage
    - level of feed offered of sugar cane
    - supplementation with concentrate
    - method of presentation of foliage and mixtures of foliages
    - utilization of bamboo charcoal to reduce the anti-nutritional effect of tannins in Acacia foliage

    on feed intake, behaviour and growth rate.
- To identify the intake potential of sugar cane and three tropical foliage species by small ruminants.

Background

Feed intake is one of the most important factors for the productivity of small ruminants. If the voluntary intake is too low the rate of production will be depressed, resulting in requirements for maintenance becoming a very large proportion of the metabolizable energy consumed and so giving a poor efficiency of food conversion (Forbes, 1995). Three types of factors affecting feed intake of ruminants can be distinguished: factors that have to do with the animals, the feed characteristics or the environmental conditions (McDonald *et al.*, 1995). Regulation of feed intake and dietary choices combine short-term control of feeding behaviour related to the body's homeostatic and long-term control that depends on nutritional requirements and body reserves (Faverdin *et al.*, 1995). Feed factors act mainly on the short-term control. Feed quality and physical characteristics of forage, such as a dry matter (DM) content, fibre content, particle size, and resistance to fracture are known to affect ease of prehension and thus intake rate (Inoue *et al.*, 1994).

The effect of animal species and group size on performance

Sheep and goats are known to select better than large ruminants, because of a narrow bite and a slit upper lip (Peacock, 1996). Several studies have shown that goats differ from sheep in feeding behaviour, level of intake, diet selection, taste discrimination, and rate of eating due to the differences in anatomy and physiology (Ngwa *et al.*, 2000; Lu *et al.*, 2005). According to Gordon & Illius (1988) goats have an incisor arcade that is narrower and more pointed than that of sheep. In some breeds, there are other special characteristics such as long, pendulous, drooping ears and shorter upper jaw compared to lower jaw making them to prefer to browse rather than to graze like other ruminants, since the lower lip touches the ground first (Rout *et al.*, 2002). Ngwa *et al.* (2000) found that forage from tree species contributed about 75% of the diet of the goats, while the reverse was true for sheep. Goats can also attain higher bite rates than sheep, which suggests a higher chewing efficiency or willingness to swallow larger particles (Domingue *et al.*, 1991). Nitrogen (N) concentration in simulated grazed forage samples was greater for goats than for sheep, and the concentration of neutral detergent fibre (NDF) was markedly less in the samples from goats than for sheep (Animut *et al.*, 2005). The difference in nutrient concentration between goats and sheep in this case was due to a difference in the proportion of grasses versus forbs.

Sheep are thought to be colour-blind, although their eyes do possess cones. Sheep can see food in front of them very clearly and can make quite complex discriminations between shapes. They can be trained to associate non-food objects with food, but this association only develops for foods that the animals have found previously to have pleasant consequences when eaten, not those that have cause discomfort after eating. Temporary covering of the eyes does not interfere with the preference for herbage species by grazing sheep, suggesting that they use smell, taste and tactile stimuli to a great extent to discriminate between different plant species (Forbes, 1995). Church (1984) concluded that sheep prefer to be selective and are easily bored by eating the same feed every day. Goats frequently begin by sampling forages given before selecting the fractions they prefer to eat (leaves, petioles and tender stems) and goats may also spend a lot of time trying to select high quality material if the feed is of uniformly low quality. When hay is available during the whole day in confined conditions, the daily time spend eating by goats is generally longer than that of sheep, and goats spend less time ruminating during the day and much more time during the night.

Various authors have reported that the corporal development of goats and sheep is different (Morand-Fehr *et al.*, 1985, Sanz Sampelayo *et al.*, 1998). Sanz Sampelayo *et al.* (1994, 1995) found that in nutritional terms and in the growing animals fed *ad libitum*, a different voluntary feed intake, lower in kids than in lambs, a different ME requirement for maintenance, higher in kids than in lambs, a different partial efficiency of ME utilization for protein retention, higher in kids than in lambs, and overall, a different partition of retained energy between protein, higher in kids than in lambs, and fat, lower in kids than in lambs, have been identified as the causes of those differences. Sanz Sampelayo *et al.* (1998) confirmed that goat kids utilise dietary protein with a higher efficiency than lambs, but the blood level of nitrogenous metabolites was not different between kids and lambs. On the other hand, several studies have shown goats to have higher rumen ammonia concentration than sheep when fed on low quality roughages (AFRC, 1998) and Alam *et al.* (1985) concluded that this was why goats had a higher digestible organic matter (OM) intake when offered forages with OM digestibility of less than 60%. Santra *et al.* (1998) found that the digestibility of nutrients such as OM, NDF and acid detergent fibre (ADF) were significantly higher in goats than in sheep. The reason was suggested to be the greater number of total protozoa in the rumen of goats (37.94×10^4 ml^{-1} strained rumen liquor) than the sheep (32.55×10^4 ml^{-1} strained rumen liquor). Although the total gut length in goats is lower than in the sheep, the retention time of digesta in goats is higher than in sheep which, could have contributed to the observed differences.

The digestion of DM, OM, crude protein (CP) and NDF of a diet containing tannin rich foliage was significantly higher in goats than in sheep (Ben Salem *et al.*, 2005). According to Gilboa *et al.* (1995) and Silanikove *et al.* (1996) goats are able to consume larger amounts of tannin-rich browses than sheep under similar conditions. The reason for the higher intake and higher digestibility of tannin rich foliage in goats than in sheep was suggested to be that goats have an ability to detoxify higher amounts of tannins (or other secondary compounds), which may occur by development of adaptive mechanisms in response to the presence of secondary compounds in the diet. Dominigue *et al.* (1991) showed that goats produce more protein-rich saliva during eating than sheep and Gilboa (1995) found that the parotid saliva of goats was relatively rich in proline (6.5%), glutamine (16.5%) and glycine (6.1%), which are known to enhance the affinity of proteins to tannins (Mehansho *et al.*, 1987). In addition, goats as browsers as mentioned above may have selected the parts of the foliage with a lower proportion of secondary compounds, versus sheep as grazers.

It has been suggested by several researchers that goats differ in level of feed intake from sheep both on pasture and in confined conditions. Animut *et al.* (2005) showed that goats on pasture spent less time eating and more time idling than sheep. This was suggested to be due to the botanical composition of the diets and also to the lower rate of growth of goats than sheep leading to shorter eating time and lower DM intake (DMI) in goats than in sheep. Salem *et al.* (2005) found that the voluntary intake of different foliage species differed between goats and sheep. While sheep ate more *Cassia fistula* than goats relative to body weight (BW), intakes of *Schinus molle*, *Chorissia speciosa* and *Eucalyptus camaldulensis* were significantly higher in goats. Hadjipanayiotou (1995) and Moujahed *et al.* (2005) found similar intakes between the two animal species. The differences in intake between goats and sheep are probably due to the kind of feeds offered, since goats and sheep have different preferences.

The presence of competition for feed and feeding space has a major influence on feeding behaviour, rate of eating being increased when there are more animals per feeder. Insufficient feed intake occurs even in the case of a well-balanced feed available *ad libitum*. Many farm species show social synchrony of feeding and it is possible that some individuals can not get to the trough during these feeding periods, sometime being excluded by dominant members of the group (Young & Lawrence, 1994). Chua *et al.* (2002) suggested that under normal farm conditions, keeping dairy calves in groups may provide several advantages to both the producer and the calves. Specifically, group rearing allows for early social interactions that have been shown to be important in the development of normal social responses later in the life. Group housing also provides improved access to space that, together with social contact, facilitates the expression of play behaviour. Grouping calves may also reduce the labour associated with cleaning calf pens and calf feeding. In contrast to group housing, individual housing had some advantages, such as higher weight gain (Maatje *et al.*, 1993), a lower incidence of disease (Weary, 2002), and fewer behavioural problems such as cross-suckling (Babu *et al.*, 2004). The success of group or individual housing will depend on many factors, including the feeding method and the number of animals in the group. According to Chua *et al.* (2002) paired-housed calves remained healthy and gained weight rapidly before and after weaning and there was no difference in weight gain between pair-housed calves or individual housed calves.

Utilization of whole sugar cane (WSC) and some foliage species as feeds for ruminants

Browse fodder is a potential inexpensive locally produced protein supplement for ruminants, particularly during the critical periods of the year when the quantity and quality of herbage is limited. It is high in nitrogen and can correct nitrogen deficiency in herbaceous vegetation during the dry season (Le Houerou, 1978). Jackfruit (JF, *Artocarpus heterophyllus*), Flemingia (FM, *Flemingia macrophylla*) and Acacia (AC, *Acacia mangium*) are perennial trees which can be found in the hilly and mountainous areas where the population of small ruminants is highest. These foliages have a high nutritive value, in many cases higher than crop by-products (Mui & Preston, 2005).

Flemingia can be found from sea level up to 2000 m. The shrub can survive long dry spells and tolerates poor drainage conditions. It can adapt to acidic conditions (pH=4-6) and to soils with high soluble aluminium. It thrives on clay and lateritic soils, tolerates light shade and to some extent fires, and has deep roots. This root system is useful as a cover, particularly with improvements of soil aeration. On farm, Flemingia is used for mulching, weed control and soil protection. The annual biomass yield of Flemingia was low in the first year after planting (17.9 tonnes/ha with 3 cuttings) and increased dramatically in the second year (60.7 tonnes/ha with 6 cuttings) (Tien *et al.*, 1997). The foliage has in addition high CP values ranging from 14% to 18% (Binh *et al.*, 1998). Flemingia could be of interest as a feed, and when used in the diet of growing goats 17% of DM as Flemingia gave the best growth rates (Mui *et al.*, 2001) and when fed together with Jackfruit foliage in the diet for ewes in late pregnancy resulted in good ewe and lamb performance and lower feed cost than the conventional diet of grass and concentrate (Van & Ledin, 2002).

Jackfruit is a multipurpose tree often planted in the garden of the farm. The fruits are used for human consumption and have high vitamin content. The foliage is used as an animal feed and when the tree is big enough, it will be used as building material. Annual yield of foliages from 10 year old trees was about 150 to 250 kg/tree, and assuming a population of 250 trees/ha this is equivalent to a fresh matter yield of 37-63 tonnes/ha (Tien *et al.*, 1997). Jackfruit leaves also appear to be an excellent feed for small ruminants, with a high nutritive value, and are a good source of minerals (Keir *et al.*, 1997; Mui *et al.*, 2002; Van & Ledin, 2002). The DMI of Jackfruit by goats ranges from 38.5 to 49.7 g per kg BW (Keir *et al.*, 1997; Mui *et al.*, 2001; Kouch *et al.*, 2003). The total tannin content of Jackfruit foliage (consisting of leaves and 35-40 cm of the twigs) was 33.2 g per kg DM (Mui *et al.*, 2002).

Acacia is a multipurpose tree widespread in hilly and mountainous areas in South East Asia. It is used for soil fixation, as a fuel, wood or fence plant and is available throughout the year. Acacia is also a fast growing species, which can maintain active growth during the dry season (Man *et al.*, 1995; Hua & Bee-Lian, 2000). The green biomass yields in three harvests up to 16 months after planting was 20.7 tonnes/ha (Man *et al.*, 1995). The content of CP in Acacia foliage is relatively high, around 170 g per kg DM, but the intake of Acacia by goats is low compared to other shrubs (Man *et al.*, 1995; Duyen *et al.*, 1996).

Sugar cane (Saccharum officinarum) has characteristics which make it superior to almost all other forage crops. The quantity and nutritional quality increase with the harvest interval, with optimum nutritive values being reached at harvesting time. Sugar cane is a perennial plant widely tolerant of different soil and climatic characteristics and has a higher biomass yield than many other forage crops. According to Mui *et al.* (1997), the annual yield of edible fresh biomass of sugar cane was 87 tonnes and 93 tonnes/ha for the first and the second harvesting years, respectively. Unlike almost all other grasses, the overall digestibility of sugar cane does not decrease with maturity; rather there is a slight increase, since accumulation of soluble cell contents (sugars) more than offsets the decline in cell wall digestibility (Alvarez & Preston, 1976). These properties make sugar cane interesting as a feed in tropical areas. However, sugar cane has high fibre content in the rind, which has a negative influence on feed intake, and also a low protein content. According to Mui *et al.* (2000) when sugar cane stems were chopped into small slices (1-3 cm lengths) feed intake was increased compared to 15 and 20 cm cutting lengths.

The effect of tannin level in fodder shrubs on nutritive value and animal performance and attempts to deactivate tannins in fodder shrubs

Most tropical browse species used as animal feed contain substantial amounts of phenolic compounds, mainly tannins, as well as other secondary compounds (Makkar, 2003; Ben Salem *et al.*, 2005). The existence of tannins in the feeds could reduce their nutritional value, as tannins bind to feed proteins thereby making them unavailable to ruminal micro-organisms, but this negative effect depends on the kind of tannins. Mueller-Harvey (2005) concluded that hydrolysable tannins are harmful, but condensed tannins (CT) are safe as long as they account for less than 5% of the DM in feed. There is an inverse relationship between high CT level in forages (more than 50 g CT/kg DM) and their palatability, voluntary intake, digestibility and N retention in ruminants (Silanikove *et* *al.*, 1996). However, a low level of tannin will improve nitrogen utilization by ruminants since many tannins can alter the site of protein digestion and thereby improve amino acid absorption (Jones & Mangan, 1977; Perez-Maldonado & Norton, 1996). This has been referred to as rumen escape protein and leads to higher growth rates, milk yield and fertility (Mueller-Harvey, 2005) since tannins form stable and insoluble complexes with proteins at pH 3.5-7.0, but these complexes dissociate at pH<3.5 (Jones & Mangan, 1977). Therefore, dietary proteins fixed to tannins escape rumen degradation and are released in the abomasum. Absorption of amino acids from the small intestine would then be possible. According to Waghorn *et al.* (1999) the presence of CT at dietary concentrations below approximately 100 g/kg DM in the diet may increase the performance of the ruminant. Min *et al.* (2003) summarised that dietary concentrations of CT, ranging from 20 to 45 g/kg DM, improved efficiency of N use and increased the daily weight gain in lambs on temperate fresh forages like Lotus cornicalatus. Barry *et al.* (1986) reported that the optimal balance between the positive and negative effect of CT was achieved in sheep when their dietary concentration was 3-4%. Several tannin-rich legumes (Makkar, 2003) and Acacia (Ben Salem *et al.*, 2005) were suggested to be used advantageously to increase bypass protein to improve ruminant performance. Several fodder shrubs and tree leaves have been shown to be able to partially or totally replace concentrate feeds without decreasing digestion or growth of sheep and goats (Mui *et al.*, 2002; Dung *et al.*, 2005).

There are many methods used to deactivate tannins and other secondary compounds in temperate and tropical forages in order to improve the nutritive value of these feeds. The methods are based on the theory that tannins are hydrosoluble polymers, which form complexes, essentially with proteins. These complexes are broken under conditions of high acidity (pH<3.5) or high alkalinity (pH>7.5). Russel & Lolley (1989) and Makkar & Singh (1993) found that treatment of tanniniferous feed sources with alkalis (urea, sodium hydroxide, potassium hydroxide, etc.) and oxidizing agents (potassium dichromate, potassium permanganate, etc) decreased their total extractable phenols and tannins and/or condensed tannins contents. However, the main disadvantage of these chemical treatments is the loss of soluble nutrients. Ben Salem *et al.* (2005) found that soaking Acacia in Acacia wood ash solution (120 g of wood ash DM/L of water, pH=12.4) decreased total extractable phenols, total extractable tannins and extractable condensed tannins, but also reduced OM and CP content. Feeding Acacia treated with wood ash solution did not affect intake and OM digestibility of the diet, but increased CP and NDF digestibility of Barbarine rams.

The benefits from the use of polyethylene glycol (PEG) as tannin-inactivating agent are well documented. PEG is an inert and unabsorbed molecule that can form a stable complex with tannins, preventing the binding between tannins and protein (Decandia *et al.*, 2000). Therefore, PEG releases forage proteins from tannin-protein complexes and improves their nutritional value leading to improved performance of sheep and goats. According to Ben Salem *et al.* (1999) the intake of *Acacia cyanophylla* by sheep increased as the level of PEG increased and PEG inactivated the condensed tannins in *Acacia cyanophylla*, thus improving microbial organism synthesis and growth of sheep. Decandia *et al.* (2000) found that PEG did not affect the diet intake but the CP digestibility of the diet increased from 37% without PEG to 71% with 50 g of PEG/day in goats fed *ad libitum* with foliage of *Pistacia lentiscu*. However, the high cost of this reagent limits its use in practice and in some cases utilization of alkalis, oxidizing agents and PEG could contribute to environmental pollution.

Charcoal as a powder or as tablets has been widely used among humans for centuries to cure indigestion and, more importantly, as an antidote to detoxify poisons. It is also used as an antidote in veterinary medicine (Cooney, 1995). Mturi (1991, 1993) suggested that the habit of eating wood charcoal by the Zanzibar red colobus monkey (*Procolobus kirkii*), which consumes a diet of foliages containing high levels of phenolic material, is known to reduce or eliminate such toxicity by binding part of the phenolic compounds to the charcoal, thus preventing their gastrointestinal absorption. Charcoal has also been used in the diets for livestock to reduce anti-nutritional effects of secondary compounds in feeds. According Poage *et al.* (2000) lambs fed bitterweed (*Hymenoxys odorata* DC) alone consumed considerably less than lambs that received bitterweed with activated charcoal and higher doses of activated charcoal resulted in higher consumption of bitterweed. The effects of charcoal on elimination of harmful substances are reported to be due to the adsorption of a wide range of compounds such as phenols, alkaloids and salicylates (Struhsaker *et al.*, 1997; Banner *et al.*, 2000; Poage *et al.*, 2000).

Effect of particle size on performance

Physical form of forage may influence productive performance through the influence on mastication, microbial fermentation in the rumen, and the rate of passage and digestion in the gastro-intestinal tract (Lu *et al.*, 2005). The method of processing the feeds, such as chopping, is also a factor which effects feed intake. When feed is chopped into short pieces, the length of the long fibres is decreased and the animals have less opportunity to select between the different parts of the feed. This leads to increased feed intake and reduced time for eating. However, when grass or hay is offered in long, unchopped form the animals have more opportunity to select between stem and leaf, which leads to increased nutritive value of the feed consumed and increased time for eating. According to ARC (1980) small ruminants are much more sensitive to particle size than cattle. Bhargarva (1988) observed that when sheep were given unchopped barley straw in sufficient amounts the consumption of the leaf parts increased. Kenney & Black (1984) found that reducing the length of forage particles increases intake rate and preference for the short material. This principle appears to hold irrespective of the DM content of the forage. Omokanye *et al.* (2001) found that chopping of browse species before offering enhanced intake by around 60%.

Effect of concentrate supplementation and level of feed offered on performance

Concentrate usually means high quality, low fiber feeds including cereals and milling by-products. Conventional classification defines concentrate as a feed containing less than 18% crude fiber. However, crude fiber analysis does not include lignin and hemicellulose, so this division is not correct. According to McDonald *et al.* (1995), the effect of adding a concentrate supplement to roughage on intake depends on the digestibility of that roughage. Concentrate added to roughages of low digestibility tends to be consumed in addition to the roughage since supplementing of concentrate stimulates micro-organism function in the rumen, reduces retention time and thus increases the intake of poor quality feed.

Generally an increased level of feeding will lead to better possibilities for selection and a higher feed intake. Increasing the proportion of legume led to significant increases in intake and in N-balance at every level of trifolium supplementation, but digestibility was not changed (Mosi & Butterworth., 1985). Wahed *et al.* (1990) found that intake of straw by sheep increased from 6.6 to 10.5 and 12.7 g/kg BW/day. However, increasing the amount of feed offered resulted in increasing rates of straw refused. It was hypothesized that the increased intake was due to animals selecting for the more rumen-degradable leaf and sheath component (Bhargava *et al.*, 1988). Kenney & Black (1984) found that the basal level of nutrition can affect the rate of intake of forage by sheep. There was a tendency for the highest intake rate to occur on the middle level of feeding. The rate at which these forages were eaten by sheep on the highest level of feeding was about 90% of that observed at the middle level of feeding. The major problem in evaluating the intake of a food lies in the reasons for which an animal may refuse the food. One reason could be palatability, which is defined as the pleasing or satisfying aspect of a feed. An animal is unable to communicate its likes and dislikes, thus it is not easy to distinguish whether palatability or a physiological reason has caused the feed rejection.

Effect of processing method of foliages on chemical composition and feed intake

Drying *Acacia cyanophylla* foliage under shade or in the sun reduced the CT content, but sun drying was more efficient than drying in the shade (Ben Salem *et al.*, 1999). The reason could be that drying probably resulted in a complex formation between tannins and protein and/or oxidation of tannins causing a decrease of extractable CT concentration in Acacia foliage (Goldstein & Swain, 1963). Ben Salem *et al.* (1997) found that DMI of sheep fed field dried *Acacia cyanophylla* foliage was higher than that of sheep fed fresh Acacia foliage, but digestibility and ruminal fermention of sheep were similar between two the forms of Acacia foliage. However, according to Ben Salem *et al.* (1999) voluntary intake of dried *Acacia cyanophylla* foliage by growing or adult sheep did not differ from fresh Acacia foliage. The disagreement between the two studies above was suggested to be due to the difference of ingredients in the diets in the studies since in Ben Salem *et al.* (1997) dried Acacia was mixed with high quality roughage eg. lucerne hay, while in Ben Salem *et al.* (1999) Acacia foliage was used as a sole roughage in the diet.

Effect of tannins on parasites

CT are known to have an ability to reduce the number of internal parasites. The beneficial effects of tanniferous plants on internal parasites could be due to one, or a combination, of factors. Firstly, tannins may form non-biodegradable complexes with protein in the rumen, which dissociate at low pH in the abomasum, to release more protein for metabolism in the small intestine of ruminants. This indirectly improves host resistance and resilience to nematode parasite infections. Secondly, tannins may have a direct anthelmintic effect on resident worm populations in animals and thirdly, tannins and/or metabolites in dung may have a direct effect on the viability of the free-living stages (Waller, 2006). Many experiments have shown that faecal egg count (FEC), parasite numbers or migration are reduced by tannin containing feeds such as cassava leaves, *Acacia brevispia* or *Desmonium ovalifolium*. According to Seng & Rodriguez (2001) the lowest level of nematode parasites (number of eggs/g faeces) was obtained when confined goats were supplemented with cassava leaves rather than three other foliages in diets based on brewer's grain. Dung *et al.* (2005) found that increasing levels of cassava hay in the diets decreased the number of Nematoda eggs and Coccidia oocysts in the faeces, but had no effect on the number of Cestoda eggs. Mui *et al.* (2005) concluded that CT have biological effects on the control of gastrointestinal parasites; possible direct effects could be mediated through CT–nematode interactions, which reduce nematode viability. Recent studies in Vietnam have reported that anti-parasitic agents extracted from plant materials have been shown to have an effect on parasites in goats and have been introduced in practice as *Citrullus vulgaris* for tapeworms, *Gliricida sepium* and *Artocarpus heterophyllus* for common intestinal worms, and Areca catechu for liver fluke. The strongyle egg counts and coccidial oocyt counts were much lower in goats fed foliage of Leucaena, Jackfruit and Cassava in comparison with goats fed Guinea grass and Ruzi grass. This indicates a reduced need for anthelmintic drugs to control gastrointestinal parasites in goats fed CT-containing foliage.

Summary of materials and methods

Location and climate of the study area

The studies were conducted at the Goat and Rabbit Research Centre, Sontay, Hatay province in Northern Vietnam. The centre is located in the buffer zone between a mountainous area and the Red River delta at E105^{o}25' longitude and N21^{o}06' latitude, with a mean altitude of 220 m above sea level. The climate is tropical monsoon with a wet season between April and November and a dry season from December to March. Average annual rainfall is 1870 mm and the mean temperature ranges from 24 to 30^{o}C.

Experimental animals, feeds and management

The animals used were growing goat kids and growing lambs. The local sheep breed Phan Rang was used in all studies with sheep. The goat breeds and crosses used were Bachthao breed and F1 (Barbari (or Jumnapari) x Bachthao) in Paper **I**, Barbari and Jumnapari breeds or F1 (Barbari x Bachthao) in Paper **II**, F1 (Boer x Barbari) in the digestibility trial in Paper **III** and Barbari pure breed and F1 (Barbari x Bachthao) in the second experiment in Paper **III**, and Bachthao pure breed or F1 (Bachthao x Barbari) in Paper **IV**. All the animals were weaned at 14 to 20 weeks of age at the start of the experiments, except for the goats used in the digestibility trial in Paper **III**, that were 26 weeks of age. The number of males and females was balanced in Papers **I**, **II** and **IV**, while in Exp. 2 of Paper **III** the number of males and females was unbalanced (24 males and 18 females). In the digestibility trial in Paper **III**, all goats were males.

Before commencement of the experiment, all the animals were vaccinated against pasteurellosis and enterotoxemia and treated against internal parasites using Wormital (Albendazole).

Whole sugar cane, concentrate and the foliage species Jackfruit, Flemingia and Acacia and Para grass (Brachiaria mutica) were used in the diets.

In Paper **I**, WSC was harvested at 12 months of age. Before feeding, WSC was chopped into two different ways as 1) slices (1-3cm) or 2) 20 cm lengths split into four parts. The concentrate consisted of 61% soybean meal and 39% rice bran. In Exp.1, WSC was offered at a level of 5% of initial BW. In Exp.2, WSC was offered at the levels of 4%, 5%, 6% or 7% of initial BW in DM according to the different treatments. Concentrate in both experiments was fed at a level of 1% of initial BW in DM.

In Paper **II**, the foliage species used were Jackfruit, Flemingia and Acacia. The foliages were prepared in four different ways. Whole foliage was tied with a steel wire in bunches. Some of the bunches had the leaves removed and others were chopped into pieces of 1-2 cm length. The concentrate was a commercial concentrate. The animals were fed foliage ad libitum equal to 130% of the fresh intake of the previous day, and concentrate was given at a level of 1% of initial BW in DM. The rations were calculated individually

In Paper **III**, Acacia foliages were prepared in three different ways: fresh, wilted or dried and were hung on the wall of the pen. Para grass was chopped into pieces of 10 to 12 cm. The charcoal was produced from bamboo wood. The amount of Acacia offered was equal to 130% of the intake of the previous day in Exp.1 and 150% of the average intake the previous week in Exp.2. Para grass and a commercial concentrate were fed at the same amount, equal to 1% of initial BW in DM.

In Paper **IV**, only Jackfruit foliage was used in Exp.1, and a mixture of foliages from Jackfruit and Acacia in Exp.2. The foliages were tied in the trough (for Exp.1) or hung together on the wall (for Exp.2). WSC was chopped into slices of 1-3 cm length. The amount of foliages offered was the same as in Paper **II**. WSC and a commercial concentrate were given in amounts equal to 1% of initial BW.

In all four papers, the animals were fed four times per day, twice in the morning and twice in the afternoon. Water and a mineral lick block were available at all times. The animals were placed in single pens in Paper **I**, **II** and **III**, and in group pens in Paper **IV**. The animals were exercised once daily for one hour in the afternoon in Paper **I** and **II**, but alternately exercised according to sex once daily for one hour in the morning or in the afternoon in Paper **III** and **IV**.

The animals were weighed in the morning before feeding at the start and every second week for the growth experiments of Paper **III** and Paper **IV**. For the rest of the experiments, they were weighed at the start and the end of the experiments or at the end of each period of the experiment, always in the morning before feeding

Experimental design

A two-factor experimental design was used for Exp. 1 of Paper **I**, Paper **II**, Paper **IV** and the growth experiment of Paper **III**.

A four-factor experimental design was used for Exp. 2 of Paper **I**. For the digestibility trial in Paper **III** a 4 x 4 Latin square design was used.

In Exp.1 of Paper **I**, animal species (kids and lambs) and physical forms of WSC (slices (1-3 cm) or 20 cm lengths split into four parts) were factors. Eight animals were used for each factor combination. The animals were fed WSC as the sole feed at a level of 5% of the initial BW. During the last 3 days of the experiment, four animals from each factor combination were chosen for observations of eating behaviour. In Exp.2 of Paper **I**, the four experimental factors were animal species (kids and lambs), level of WSC offered (4, 5, 6 or 7% of initial BW), physical form of WSC (slices (1-3 cm) or 20 cm lengths split into four parts) and concentrate supplementation (with or without). Two animals were used for each factor combination. The time for both experiments was 15 days, with the last 7 days for data collection.

In Exp. 1 of Paper **II**, 48 kids were used in two experimental periods. In each period, the animals were randomly allotted to four methods of presentation as 1) whole foliages chopped and put in the trough (chop) 2) whole foliage hanging from the wall of the pen (hang) 3) whole foliage tied in the trough (tie) 4) leaves stripped and placed in the trough together with tied twigs (strip). Each method was tested on 3 different foliages (Jackfruit, Flemingia and Acacia) each offered as a single feed. In Exp. 2, 64 kids were randomly allotted to 4 treatment groups according to different foliage species combinations: 1) 500 g Jackfruit+500 g Flemingia/kg foliage; 2) 500 g Jackfruit+500 g Acacia/kg foliage; 3) 500 g Flemingia+500 g Acacia/kg foliage; 4) 330 g Jackfruit+330 g Flemingia+330 g Acacia/kg foliage. The foliages were mixed (tied together in the same bunch) and presented to the goats in two different ways, either as whole foliage hanging from the wall of the pen (hang) or tied in the trough (tie). The experimental time for Exp. 2 and the first period of Exp 1 was 21 days, with a 14-day adaptation period and the following 7 days for data collection. After each period in Exp. 1, the animals were allowed 10 days of normal feeding of fresh grass and concentrate. During the last three days of each period in Exp.1, two kids in each treatment were chosen from each experimental group for observations of behaviour.

In Paper **III**, In Exp.1 (digestibility trial), the effect of different levels of bamboo charcoal on digestibility and nitrogen balance was estimated. The treatments were: 1) Control, no bamboo charcoal; 2) 0.5 g bamboo charcoal per kg BW; 3) 1.0 g bamboo charcoal per kg BW; 4) 1.5 g bamboo charcoal per kg BW. In Exp.2 (the growth experiment), 42 goats were randomly allotted into 6 different treatment groups. The treatments were three different methods of processing Acacia and addition or no addition of bamboo charcoal. The processing methods were: (1) fresh foliage (2) wilted foliage and (3) dried foliage. Each method was tested with or without adding bamboo charcoal (0.5 g charcoal/kg BW).

In Paper **IV**, 30 kids and 30 lambs were used in the same design in 3 experimental periods of Exp. 1. In each period, animals were randomly divided into 5 treatment groups according to group size of one to five animals per pen. During the last 4 days of each data collection period, 15 animals were alternately chosen for observations of aggressive behaviour. In Exp. 2 (growth experiment), 36 kids and 36 lambs were randomly allocated to two treatment groups, 6 pens with one animal per pen and 6 pens with five animals per pen.

Measurements and chemical analysis

In Paper **I**, Paper **II** and in the two first experiments of Paper **III** and Paper **IV**, the feed offered, feed refused and water consumption were recorded daily after the adaptation periods. The feed samples were taken daily during the collection periods and pooled to weekly samples for analysis.

In the growth experiments of Paper **III** and Paper **IV**, the feed offered, feed refused and water consumption were recorded daily during 12 weeks of the experiments. Samples of feed offered and refused were taken weekly, then pooled to monthly samples for analysis.

In the digestibility trial of Paper **III**, the faeces voided and urine excreted by each animal were recorded twice a day. 10% of the faeces was sampled at each collecting time, and stored frozen prior to analysis. Urine was collected in a jar containing 50 to 100 ml of 10% sulphuric acid to preserve the nitrogen and 10% urine at each collecting time was also sampled and stored at 4°C for analysis.

The samples were analysed for DM, CP, NDF, ADF, ash and total tannins. DM (967.03), CP (984.13), ADF (973.18) and ash (942.05) were analysed according to the standard methods of AOAC (1990). NDF was determined by the method of Van Soest *et al.* (1991) using sodium sulfite and amylase, and was expressed with residual ash. Total tannins (30.018) were analysed according to the method of AOAC (1975) and were expressed as g/kg DM.

Proportion of stems in foliage offered in Exp. 1 of Paper **II** was done four times per day and proportion of stems in foliage refused was done once a day in the morning during the data collection period of each experimental period.

In the study of eating behaviour, the duration of the eating and eating bouts and the duration of rumination and rumination bouts were studied during the last 72 hours of Exp. 1 of Paper **I** and each period of Exp. 1 of Paper **II**. In the study of eating mode (Exp. 1 of Paper **I**) the number of pieces of WSC consumed during the first 2 min of the two first eating bouts after each feeding was recorded.

The observations of aggressive behaviours in Exp.1 of Paper **IV** were run for 45, 30 and 5 minutes after each Jackfruit, sugar cane and concentrate feeding, respectively, and were done during the last four days of each experimental period. The frequency of fighting, other aggressive behaviours (including pushing, threatening and headthrusts) and displacements from the feeder were recorded.

Faecal egg count was recorded at the 10th day after deworming and then at every 4-week interval in the growth experiment of Paper **III**. Faecal samples were taken directly from the rectum in the morning for counting gastro-intestinal nematode parasite eggs. FEC was determined using the modified McMaster method (MAFF, 1977). Nematoda and Cestoda eggs and Coccidia oocysts were counted under a microscope at 10 x 10 magnification (Hansen & Perry, 1994).

Statistical analysis

The data were analysed using the GLM procedure of Minitab Software Version 12.0 (Minitab, 1998; Paper **I** and **II**) and Minitab Software Version 14.0 (Minitab, 2003; Paper **III** and **IV**).

Treatment means which showed significant differences at the probability level of $P<0.05$ were compared using Tukey's pairwise comparison procedures in all experiments except Exp.1, Paper **IV**. Initial BW was used as a covariate factor in the models in Paper **I**, Paper **II** and the growth experiment of Paper **III**.

Orthogonal contrasts were used to test for linear, quadratic and cubic effects of group size in Exp.1, Paper **IV** by using the regression procedure of Minitab Software Version 14.0 (Minitab, 2004).

The relationships between level of WSC offered (Exp.2, Paper **I**) or eating time (Exp.1, Paper **II**) and DM feed intake were determined using the linear responses in the Fitted Line Plot procedure of Minitab 12.0.

The FEC data (Exp.2, Paper **III**) and parts of the aggressive behaviour data (Exp.1, Paper **IV**), which contained many zeros were analysed using $\log_{10}$ (FEC + 1) and ln(x +1) transformation, respectively. All statistical tests were applied to the transformed data.

Summary of results

The effects of animal species on feed intake, selection and aggressive behaviour in goat kids and lambs (Papers I and IV)

Differences in DMI between goats and sheep changed according to the ingredients of offered diets, feedstuffs and levels of feed offered. When animals were fed WSC as the sole roughage in the diet, kids had higher DMI of WSC than lambs (31 g versus 23 g/kg metabolic weight ($W^{0.75}$) in Exp. 1 and 46 g versus 40 g/kg$W^{0.75}$ in Exp. 2, Paper **I**). The DMI of WSC of lambs was highest when WSC was offered at 6% of body weight, while DMI of WSC of kids was not significantly changed as the amount of WSC offered was increased (Exp.2, Paper **I**). When animals were fed a diet consisting of Jackfruit foliage (Exp. 1, Paper **IV**), the kids had a significantly higher total DMI than lambs (50 g versus 47 g/kg BW), whereas there was no significant difference in total DMI between the species (31 g and 31 g/kg BW, respectively) when they were fed a diet consisting of a mixture of JF+AC foliages (Exp. 2, Paper **IV**). The DMI of Jackfruit foliage in the diet of kids was significantly higher than that of lambs (39 g versus 33 g/kg BW in Exp. 1 and 15 g versus 13 g/kg BW in Exp. 2, Paper **IV**), while the DMI of WSC was higher for sheep than for goats (4 g versus 1 g/kg BW in Exp. 1 and 6 g versus 3 g/kg BW in Exp. 2, Paper **IV**).

Water consumption was significantly higher for the lambs compared to the kids (35-36 g versus 28 g/kg BW, Paper **IV**).

Both kids and lambs had an ability to consume WSC and Jackfruit foliage with higher contents of CP and ash, but lower NDF and ADF contents compared to WSC and Jackfruit foliage offered.

The daily weight gain was higher ($P<0.05$), but the FCR was lower ($P<0.001$) for the lambs compared to the kids (89 g versus 63 g weight gain and 8.8 versus 12.0 kg DM/kg BW gain in Exp. 2, Paper **IV**). The coefficient of variation for growth rate within pens in the group size of 5 animals was significantly different between the two animal species (66% and 23% for kids and lambs, respectively, in Exp.2, Paper **IV**).

The observation of eating mode of kids and lambs (Exp.1, Paper **I**) fed WSC as a sole roughage indicated that both kids and lambs had the same 4 eating modes: Eaten from two ends; inner part eaten; completely consumed; applied to the trough and broken using teeth and upper lip, but the frequency for each eating mode was different. Lambs tried to get the inner part of the sugar cane, while kids preferred to consume the whole piece of sugar cane, whether it was sliced or in 20 cm pieces. Kids spent more time eating than lambs and the number of eating bouts in kids was higher than in lambs.

Aggressive behaviours of kids and lambs (Exp.1, Paper **IV**) given a complete diet of Jackfruit, WSC and concentrate were different for different feedstuffs and the main aggressive behaviour was fighting. For the Jackfruit feeding, kids had a higher incidence of fighting ($P<0.05$) and other aggressive behaviours (pushing, threating and headthrusts) than lambs, but there was no significant difference for displacements between two animal species. The female kids showed a higher number of fighting occasions than the male kids, while the female lambs and male lambs had similar results. Sex had a significant effect on other aggressive behaviours and displacements, with male animals showing more aggressive behaviours than female animals.

For the sugar cane feeding, fighting and displacements were similar for both kids and lambs while the other aggressive behaviours were significantly higher ($P<0.05$) for kids than for lambs. For the concentrate feeding, both kids and lambs showed a similar behaviour.

Group size (Paper IV)

Total DMI (Exp. 1) increased linearly as the number of animals in the pen increased. DMI of Jackfruit also increased linearly with increasing group size. There were no linear, quadratic or cubic relations between chemical composition and group size. Weight gain and water intake were not affected by the group size. There was no significant effect of interactions, period or sex on any of the variables concerning DMI, water intake or weight gain.

In Exp. 2, total DMI and DMI of Jackfruit and Acacia foliage and WSC were similar for the animals in the group pens and in the individual pens. There was an interaction between animal species and group size in relation to total DMI and DMI of Jackfruit, indicating that goats showed a higher intake in group pens while lambs consumed more in single pens. Animals in the pens of 5 animals drank more water than those in the pens with one animal (35 g versus 28 g/kg BW). The weight gain and feed conversion ratio was similar for animals in group and individual pens.

During eating Jackfruit and WSC, the number of aggressive occasions per pen or per animal increased linearly as the number of animals in the pens increased. When eating concentrate, there was no significant linear or quadratic relation between group size and number of fighting occasions or other aggressive behaviours.

WSC and foliage species (Paper I and Paper II)

WSC had a very low CP content (25 g CP/kgDM), but relatively high NDF and ADF contents (400-451 g NDF/kg DM and 246-333 g ADF/kg DM).

Flemingia had the highest CP content (210 g/kg DM) and lowest tannin content (28 g/kg DM), while Jackfruit had a lower CP content (133 g/kg DM) and also lower tannin content (42 g/kg DM) than Acacia (162 g CP and 49 g tannins/kg DM). Contents of DM, CP, ash and tannins were higher in leaves+petioles than in the stems. In contrast, NDF and ADF were higher in stems than in leaves+petioles. The stem proportion was highest in the Flemingia foliage and lowest in the Acacia foliage (270g, 248 g and 141 g/kg foliage for Flemingia, Jackfruit and Acacia, respectively).

The intake potential of these feeds by goats was different for different foliage species (Paper **I** and Paper **II**). Jackfruit foliage showed the highest intake potential (92 g DM/kg$W^{0.75}$) and Acacia the lowest (20 g

DM/kgW$^{0.75}$). The intake potential of WSC by sheep was 23 to 40 g DM/kgW$^{0.75}$. The concentrate was completely consumed in all studies.

Total eating time of kids and lambs fed WSC as a sole roughage at 5% of BW differed for the different processing methods, 283-397 minutes and 256-310 minutes for kids and lambs, respectively. Total rumination time was the same for the different processing methods, 479-515 minutes and 495-532 minutes for kids and lambs, respectively.

The total eating time was longer for kids fed Jackfruit foliage than for kids fed Flemingia or Acacia foliage (385 minutes, 297 minutes and 202 minutes for Jackfruit, Flemingia and Acacia foliage, respectively). In general a longer eating time led to a higher DMI by kids. The pattern of total rumination time was the same for the eating time, 482 minutes, 450 minutes and 331 minutes for Jackfruit, Flemingia and Acacia foliage, respectively.

Processing of WSC and Acacia (Paper I and Paper III)

Processing method of WSC affected the amount of DMI of WSC (Paper **I**). Both kids and lambs fed WSC chopped into slices of 1-3 cm had higher daily DMI than those fed WSC chopped into 20 cm lengths split into four parts (30 g versus 25 g/kgW$^{0.75}$, Exp. 1, Paper **I**). Total eating time of animals fed WSC cut into 20 cm pieces was longer than that of animals fed with 1-3 cm pieces, but total rumination time was the same for these two chopping lengths.

The processing method of Acacia foliage had a significant effect on total DM intake and DM intake of Acacia by goats (Paper **III**). Total DM intake of goats in the treatment with wilted Acacia (70 g/kg W$^{0.75}$) was significantly higher than that in the treatments with fresh and dry foliage (64 versus 63 g/kg W$^{0.75}$). DM intake of fresh Acacia was similar to DM intake of dry Acacia (28 versus 26 g/kg W$^{0.75}$), and significantly lower than DM intake of wilted Acacia (33 g/kg W$^{0.75}$).

Wilting or drying Acacia foliage increased the NDF content compared to fresh Acacia. Total tannins of Acacia foliage after wilting or drying were lower than that in fresh Acacia. However, the changes in NDF and CP contents were not significant.

The weight gain of goats fed wilted or dry Acacia was higher than that of goats fed fresh Acacia, but the difference was not significant, and was 43, 51 and 50 g/day for fresh, wilted and dried foliage, respectively.

Levels of WSC offered and supplementation with concentrate (Paper I)

WSC feeding levels between 4% and 7 % of initial BW had no effect on the DMI of kids and the chemical composition of feed consumed showed no clear tendency in relation to level of WSC offered. Lambs had the highest intake when fed at 6% BW, and the highest CP contents of the sugar cane consumed was at the level of 4%.

The addition of concentrate did not significantly increase DMI of WSC, but did increase total DMI.

Method of presentation of foliage and mixtures (Paper II)

Hanging the foliages from the wall of the pen or tying in the trough resulted in higher intake, while chopping gave the lowest intake. With low intake potential foliage species, such as Flemingia and Acacia, the hanging method resulted in the highest feed intake by goats. In contrast, with high intake potential foliage species, such as Jackfruit foliage, the tying method showed the highest feed intake. The highest consumption of stem was obtained when feeding the foliage with the leaves stripped and placed together with the tied twigs in the trough. The consumed foliage of Acacia had the highest proportion of stem with the chopping, while Flemingia had highest proportion of stem with the tying and stripping methods.

Total eating time of kids fed foliage hung, tied or stripped was significantly higher than that of kids fed chopped foliage, but there was no significant difference in eating time among these methods. Kids fed Acacia or Flemingia hanging showed the longest eating time, while the shortest eating time was found in kids fed Jackfruit hanging.

Kids fed with mixtures of (Jackfruit + Flemingia) or (Jackfruit + Flemingia + Acacia) had higher intakes than those fed with mixtures of (Jackfruit + Acacia) or (Flemingia + Acacia) (84 g, 58 g, 49 g and 29 g DMI/kgW$^{0.75}$ for the mixtures, respectively). DMI of kids fed mixtures of Jackfruit + Flemingia or Flemingia + Acacia was higher with the hanging method than with the tying method, while the opposite was the case for the mixtures of Jackfruit + Acacia or Jackfruit + Flemingia + Acacia. The proportion of each foliage species in the consumed mixtures was different from the offered mixture. The proportion of foliage species/kg feed intake changed to 550 g Jackfruit +450 g Flemingia, 630 g Jackfruit +370 g Acacia, 660 g Flemingia +340 g Acacia and 400 g Jackfruit +370 g Flemingia +230 g Acacia. Kids tended to increase the amount of high intake potential foliage species such as Jackfruit foliage, and to decrease the amount of low intake potential foliage species such as Flemingia and Acacia. In all mixtures, animals consumed foliage with lower proportion of stem.

Bamboo charcoal levels (Paper III)

The addition of bamboo charcoal in the diet of kids did not increase the total DMI or the DMI of Acacia foliage compared to the diet without bamboo charcoal addition.

Kids supplemented with 0.5 or 1.0 g charcoal/kg BW had a significantly higher DM and OM digestibility than kids supplemented with 1.5 g charcoal/kg BW or without supplementation. Adding bamboo charcoal to the diet increased CP digestibility compared to the diet without bamboo addition, but did not increase NDF or ADF digestibility.

N retained in g/day was highest in goats fed a diet with 1.0 g charcoal/kg BW and lowest in the control treatment. Kids fed with 0.5 g charcoal/kg BW had similar N retained as goats fed 1.0 or 1.5 g charcoal/kg BW.

The goats fed a diet with bamboo charcoal grew significantly faster than those fed a diet without bamboo charcoal.

The inclusion of bamboo charcoal in the Acacia diets did not affect the faecal egg count of goats at any recorded time.

General discussion

Differences in feed intake between goats and sheep

Goats generally differ from sheep in DMI. However, there are different reports showing the intake of goats to be higher, lower or similar to that of sheep. Higher overall mean intake has been found by Simiane *et al.* (1981 in AFRC, 1998), 55.8 and 65.3 g DM/kg $W^{0.75}$ daily for sheep and goats, respectively; and where goat intake was 17% higher than sheep. Wahed (1987) showed that the mean intake was 59.6 and 76.8 g DM/kg $W^{0.75}$ for sheep and goats, respectively, intake of goats being 29% higher than that of sheep. Goats and sheep also differed in total shrub consumption. Goats consumed substantially more foliage than did sheep, 45.7 *vs.* 27.2 g/kg BW (Rogosic *et al.*, 2006). The total DMI in this study was 30% for the WSC diet (Paper **I**) and 6% higher for the Jackfruit diet (Exp. 1, Paper **IV**).

According to Santra *et al.* (1998), under controlled feeding as per their maintenance requirement, DMI was lower in goats compared to sheep (57.1 g *versus* 62.1 g/kg $W^{0.75}$), which could be partly due to the inherent limitation of controlled feeding influencing selective ability of goats. Aregheore (1996) found that DMI of 0.63, 0.58, 0.62 and 0.79, 0.70, 0.83 kg DM/kg $W^{0.75}$ were obtained for goats and sheep fed on groundnut shell, maize cob and cassava peel, respectively.

Similar intakes for goats and sheep were found by Moujahed *et al.* (2005) of 84.9 and 84.4 g DM/kg $W^{0.75}$ for sheep and goats fed *Acacia cyanophylla*-based diets. Hadjipanayiotou (1995) found no difference in DMI between sheep and goats when fed a diet of concentrate and barley hay (38 g DM/kg $W^{0.75}$). In Exp. 2, Paper **IV**, the total DMI was similar for goats and sheep but the DMI of Jackfruit was higher for the kids than for the lambs.

The contradictory results concerning the differences in feed intake between sheep and goats are in general, related to differences in anatomy and physiological characteristics. These differences have varying effects on feed intake, depending on the situation and the inconsistent results can probably be explained by different feeds, feed properties, feed qualities and management methods. The differences in anatomy and physiology of the digestive tract have not been studied in this thesis but also here, there are diverging opinions about the differences between sheep and goats. According to AFRC (1998), goats require a higher energy level for maintenance compared to sheep leading to a higher feed intake for goats than for sheep. The higher intake and in some cases, digestibilities in comparison with sheep may be just an effect of selection since when fed roughages with high fibre and low N content, the diet consumed by sheep contained more fibre and less N than the diet consumed by goats (Alcaide *et al.* (2000). If selection is not allowed the intake and digestibilities of roughages are probably similar in sheep and goats. Goats are considered to have a higher concentration of rumen ammonia, which could lead to a better fibre digestion (Domingue *et al.*, 1991). On the other hand, goats are thought to have a smaller proportion of the gut in relation to BW, which results in a rapid movement of digesta from the rumen and along the entire gastro-intestinal tract (Van Soest, 1982). They also have a smaller gut volume and smaller fermentation capacity and goats are not truly efficient exploiters of cellulose matter. There is also some evidence that goats pass larger particles through the alimentary tract than sheep (Aregheore, 1996), and that this could explain a higher digestibility in goats. However, when goats and sheep are fed medium or high quality forages, similar rumen retention times, digestibilities and feed intake are to be expected (Alcaide *et al.*, 2000).

The differences in anatomy and physiology mentioned above leads to differences in *e.g.* behaviour (selective behaviour, eating behaviour, social behaviour) feed preferences and water intake, which will be discussed in the following.

Effect of selective behaviour and eating behaviour on feed intake in goats and sheep

The selective ability of small ruminants is due to their special anatomical characteristics such as a very flexible, slit upper lip and prehensile tongue. Parachristou *et al.* (2005) suggested that browsing animals have lips and tongues that are very agile and can move easily to select leaves and avoid thorns when eating spiny and thorny plants on the pasture. Goats, for instance, with their mobile and narrow muzzle, can move their mouth more easily among thorns to pluck small leaves, so that thorns may be less effective in reducing cropping rates. Goats often spend a lot of time selecting high quality material if the feed offered or available is of low quality. Due to this selective process, the intake is sometimes low (Peacock, 1996). The development of selective ability of feeds with higher nutrient contents and lower NDF and ADF contents is a way to cope with the short retention time in the rumen and in the entire gastro-intestinal tract of goats and with their low fibre digestibility. Both kids and lambs in this study had an ability to consume WSC and foliages with higher CP and ash content, but lower NDF and ADF contents compared to WSC and foliage offered. Similar results were reported by Papachristou (1983), who found that goats on pasture selected diets significantly higher in CP and *in vitro* OM digestibility and lower NDF and ADF content than samples collected by hand plucking mimicking foraging of goats.

A higher level of feed offered generally results in higher feed intake. Zemmelink & t'Mannetje (2002) concluded that an increasing level of feed allowance results in higher intake and better opportunities for selection and consequently a higher nutritive value of the diet consumed. Wahed & Owen (1986) and Wahed (1987) found that goats fed untreated barley straw increased intakes by a third when animals were allowed to refuse 50% of the amount offered instead of 20%. The intake response was judged to be due to goats being able to select more leaf and less stem with the higher rate of straw offered. The response from the animal species to the different levels of WSC offered in this study was not the same. While the goats showed no differences in DMI among the four offered levels of WSC, the lambs showed the highest DMI at 6% of BW, higher than the 4 and 5% levels but not different from the 7%. It may be that sugarcane differs from other feedstuffs relative to overfeeding and selection, because of its high contents of sucrose, glucose and fructose (Preston & Leng,

1987) and that goats are different from sheep in feeding behaviour. Fedele *et al.* (2002) stated that the availability of feed in unlimited amounts did not cause an unusual intake in a group of goats given free choice. The diet feed contribution changed according to evolution of the physiological state of the goats. It is likely that there is a physical limit to the possibility for selection. At high levels of feeding the volume of fibrous feeds become large and the animal may not have possibility to search through the whole amount offered for parts of the feed with higher nutritive value. This may have been the case for the lambs in Paper **I** since they were not able to increase feed intake when more than 6% of BW was fed. It is possible that goats are more dependent on variation in feed than lambs, since they consume many different feeds every day if they have opportunity (Sanon *et al.*, 2006). In this study, goats were only fed sugar cane or sugar cane and concentrate, which may have resulted in low interest in increasing feed intake.

When eating WSC, the kids and the lambs in this study showed the same types of eating mode, but the frequency for each eating mode was different. While the kids preferred to consume the whole piece of sugar cane, the lambs liked eating the inner part of the sugar cane. It has been reported that lambs have a blind area about 30 mm in front of the nose so they cannot see exactly what they are eating, and it has been suggested that lambs use the sense of touch to decide exactly what to eat (Forbes, 1995). Lambs usually select the softest part of the plant, which often means young leaves or the inner part. The eating behaviour in this study supports the theory about the importance of touch.

Effect of differences in social behaviour on feed intake of goats and sheep

The different responses in feed intake for animal species in Paper **IV** could be due to the difference in aggressive behaviours between goats and sheep since sheep are typically social animals (Arnold, 1985) and goats have a linear hierarchic order (Hafez, 1975). The aggressive behaviour of kids and lambs differed for different feedstuffs and was greater in kids than in lambs. According to Shinde *et al.* (2004), during the first hour after each feed, the goats exhibited a higher frequency of agonistic behaviour when fed concentrate (46%) and green (36%) fodder than dry (18%) fodder. In sheep, the social environment may strongly influence some of the components of ingestive behaviour that control food intake. It was found that sheep in smaller groups spent less time grazing than sheep in larger groups. There was no relationship between group size and intra-meal intervals, prehension biting rate or number of meals, but animals in groups of one and two tended to have shorter meals than those in larger groups.

There was indirect evidence, from measurements of changes in sward surface height, to suggest that intake of herbage was also reduced for animals grazing in groups of less than four. In goats, social dominance is clearly established, quite stable and a linear hierarchic order exists in a flock of goats. High rank animals initiated most but encountered few agonistic interactions and amicable behaviour was altogether absent in the flock. Dominance value of animals was the most important factor influencing the use of feed resources especially when resources are offered under group feeding and also in short supply (Shinde *et al.*, 2004). A higher agonistic index (AGI, all agonistic interactions an individual is involved in per time unit) in dwarf goats than in pigs was reported by Langbein & Puppe (2004). The reason suggested was that the pig AGI was much lower after weaning and nearly absent at an age of about 14 weeks and the drastic reduction of overt aggression in pigs is predominantly a result of increasing familiarity of the group members rather than by their actual genetic relatedness. However, the constantly high level of overt agonistic behaviour in dwarf goats conflicts with a widely accepted assumption on the general function of social hierarchies reducing agonistic interactions in animals living in groups.

Differences in growth rate due to animal species

The daily weight gain was higher for the lambs than for the kids (Exp.2, Paper **IV**), despite the similar DMI of the two animal species. The higher weight gain in lambs than in kids could be due to differences in aggressive behaviours, genetic capacity or production systems. According to the results from the aggressive behaviour study, kids showed more aggressive behaviour than lambs and intensity of fighting by kids was observed to be much higher than in lambs. Other reasons for the difference in weight gain between kids and lambs could be the genetic capacity for growth in the species and the difference in the production systems. The kids were separated from their mothers at 10 days of age, and were allowed to suckle twice a day before weaning but with access to extra feeds. The lambs were kept together with the ewes until weaning and the ewes were given mainly low quality feeds. The lambs may thus have shown some compensatory growth.

The coefficient of variation of growth rate within pens in the group with five animals was greater for the kids than for the lambs (66% *versus* 22%), but similar for male and female pens. According to Shinde *et al.* (2004), high-ranking goats were first to occupy the trough when feed was offered and also spent more time in eating feed and fodder than medium and low-ranked animals. Low-ranking goats generally preferred to consume feed when dominant animals were idling to avoid conflict (Shinde *et al.*, 2004).

Probably the kids highest in rank were able to consume more feed than the kids with the lowest rank. At start, the weight of the kids was similar within groups but during the course of the experiment, there was an increasing difference in weight between kids of higher and lower rank due to differences in feed intake. This difference in weight and size emphasized the difficulties for the kids of low rank to consume sufficient quantities of feed. Since the kids showed more aggression than the lambs, the variation in growth was higher in the group of kids than in the group of lambs

Differences in water consumption in goats and sheep

Lambs consumed 28% more water than goats in this study (Paper **IV**). According to Ferreira *et al.* (2002), Mutton merino lambs drank 48% more water than Boer goat kids, while the percentage was 15% more in the study of Hadjigeorgiou *et al.* (2003). It has been suggested that lower water consumption in goats compared to sheep and other animals is that goats have adapted to limited water intake and short-term shortages due to low water turnover rate. The adaptation is similar to the camel, an animal that is known for its ability to go without water for long periods (Silanikove, 2000) and their greater ability to reduce evaporative loss of water, faecal water content and to concentrate urine (Robertshaw, 1982). Goats living in harsh environments represent a climax in the capacity of domestic ruminants to adjust to such areas. Factors influencing this ability include their small body size, low metabolic requirements, ability to reduce metabolism, digestive efficiency in relation to feeding strategies, efficient usage of water, as well as their ability to economize the nitrogen requirements via urea recycling and nitrogen conservation (Silanikove, 2000).

Differences in feed preferences between goats and sheep

Goats are reported to have a better ability to detoxify tannins than sheep. According to Vaithiyanathan *et al.* (2001), higher ratio of parotid gland weight to BW and trichloroacetic acid soluble proteins of parotid glands in goats than in sheep may indicate a higher ability to detoxify tannins leading to a possible higher intake of tanniferous forages. When eating goats secrete more saliva containing a higher level of nitrogen than sheep (Dominigue *et al.,* 1991).

The kids consumed different proportions of stems *versus* leaves of foliage compared to the feed offered in Paper **II** depending on feeding method. When foliage was fed separately, the tendency was for a higher proportion of stems in the consumed than offered for Acacia and Flemingia. Since the

Acacia and Flemingia stems contained less tannin, it may have been an advantage for the animals to consume more stems than leaves. Due to the ubiquity of toxins, herbivores cannot avoid eating plants containing toxins so they must limit their intake to a variety of plants that contain different kinds and amount of toxins (Provenza, 1996). Mueller-Harvey (2005) concluded that some high-tannins feeds, which produce harmful effects if fed as sole feeds, tend to be less deleterious if fed as a mixture with other tannin-containing feeds.

Goats and sheep have different preferences for feed. Karbo *et al.* (1996) reported that forage preference on pasture differed between sheep and goats. While sheep preferred *Cajanus cajan* to Leucaena, Sesbania or Gliricidia goats preferred Leucaena to Cajanus, Sesbania and Gliricidia. In addition, in this study the intake potential of feedstuffs was not the same for different feed species. Jackfruit foliage showed the highest intake potential, followed by Flemingia foliage and WSC and the lowest intake potential was from Acacia foliage. Goats preferred Jackfruit foliage to other feedstuffs. According to Mui *et al.* (2002), goats receiving Flemingia consumed a smaller amount of foliage than goats receiving Jackfruit in the wet season (21 g *versus* 41 g/kg $W^{0.75}$), but similar in the dry season (37 and 41 g/kg $W^{0.75}$). A lower DMI of *Acacia mangium* by goats compared to other foliage species as *Trichantera gigantea,* Jackfruit or Banana has been suggested by Duyen *et al.* (1996).

There are many factors affecting intake potential of feed species. Abdel-Moneim & Abd-Alla (1999) and Provenza (1996) indicated that plant characteristics such as taste, texture, nutrients, toxins and morphological structure could affect forage preference by goats. Physical characteristics of the forage such as DM content and particle size, and resistance to fracture are also known to affect ease of prehension and thus intake rate (Inoue', 1994). Palatability of feedstuffs is influenced by food composition and shape, the animals' physiological state and experience (Quaranta *et al.*, 2005). Plant morphology, which is affected by browsing, also influences browsing rates and daily feed intake (Parachristou *et al.*, 2005). Whereas plants whose leaves grow on old shoots tend to result in high bite rates and reduced food intake rate, plants with leaves that grow on young edible shoots allow bigger bite sizes and relatively high intake rates. Bite size plays a major role in influencing intake rates, therefore plants and plant parts that afford animals bigger bite sizes are likely to be preferred. Lignin and fibre contents in vegetation also affect intake (Parachristou *et al.*, 2005). The lower DMI of Acacia and Flemingia foliage compared to Jackfruit foliage could be a higher concentration of fibre (520 g; 498 g and 407 g NDF per kg DM for Flemingia; Acacia and Jackfruit foliages, respectively).

The effect of group size on feed intake

Feed intake is generally considered to increase when there is competition among animals. Keeping animals in a group provides an opportunity for social interactions between animals and also increases total available space. In this study, total DMI and DMI of Jackfruit increased linearly as the number of animals in pen increased (Exp.1, Paper **IV**). Increased DMI due to increasing group size was also found by Penning *et al.* (1993) and Sevi *et al.* (1999) in a study where stocking rate and flock size influenced grazing behaviour and feed intake. Sheep in smaller groups spent less time grazing than sheep in larger groups and the reason was suggested to be that sheep in large groups might benefit from social facilitation and/or from the increased number of individuals that are vigilant. For pig production, especially for commercial production, Spoolder *et al.* (1999) reported reduced productivity and increased aggression when group size increased. However, for suckling animals (calves and goat kids), the group size had no effect on the feed intake and weight gain but it was commented that group communication has an effect on the process of adaptation to feeds. Group pens for young ruminants also require less labour than individual pens and building costs are lower (Goetsch *et al.*, 2001; Chua *et al.*, 2002).

In the prolonged experiment (Exp.2, Paper **IV**) on the effect of group size, kids consumed more when kept in group pens than in single pens, while lambs consumed more in single pens than in group pens. The higher level of aggressive behaviours in kids than in lambs led to more competition and higher feed intake in the kids. Sheep are typically social animals and preferably eat at the same time. Space at the feeders then becomes very important to secure a high feed intake. The lambs were heavier than the goats, which must have meant less space in the pen and at the feeders per animal and this can also partly explain the lower consumption in the group pens.

The aggressive behaviour of kids and lambs expressed as both per pen or per animal during eating Jackfruit or sugar cane was increased linearly as the number of animals in the pens increased. An increase in the number of agonistic encounters with increasing numbers of animals in the pen has been reported by many researchers (Hurnik, 1982; Kondo *et al.*, 1989). According to these authors, under high density conditions animals cannot avoid violating individual distance zones, which results in increased amounts of agonistic interactions and under conditions of large group sizes, individual animals have difficulty in memorizing the social status of all members in group, which increases the incidence of aggressive interactions. In large groups, it was not only two animals involved in agonistic activities but intervention also took place (Keil & Sambraus, 1998). Intervention is defined as one animal pushing in between two fighters, and thus ending the fight. Goats that intervened in fights on several occasions usually had a high dominance index and in some cases, there was a particular relationship that existed between the intervener and one of the fighters.

The daily weight gain was similar for the animals in groups of 1 or 5 animals. Domanski *et al.* (1971) found that groups of 12, 24 or 44 lambs did not have a significant effect on body weight at 100 days of age, although lambs from the smaller groups were slightly heavier than those from the larger groups. Between 100 and 145 days of age, lambs from the smaller groups showed a poorer growth rate than those from the larger groups, presumably because the latter were better adapted to conditions in the combined flock. Penning *et al.* (1993) also found that the different groups of 1, 10 or 20 lambs had no effect on weight gain.

The animals in the pens with five animals drank more water than those in the pens with one animal. Water and feed intake are strongly correlated (Silanikove, 1989; Hadjigeorgiou *et al.*, 2003), with increased group size and increased feed intake leading to increased water intake, but this correlation was very weak in this study. The factor affecting water intake in this case was obviously not just feed intake, but also included the group size effect. According to Forkman (1996), the consumption of water is sensitive to the social behaviour in the form of competition and also social facilitation.

The effect of processing of WSC and foliages on feed intake in goats and sheep and on chemical composition of the feeds

In general, a reduction in particle size of forages causes an increase in intake rate (Kenney & Black, 1984). When WSC was chopped into small 1–3-cm pieces, the DMI of WSC was higher than when chopped into 20-cm lengths and split into 4 parts. After chopping, the length of long and hard fibres in the rind of the sugar cane was reduced thereby helping the animals to chew the feeds more easily and to choose the softer parts such as the tops of the sugar cane. Abdel-Moneim & Abd-Alla (1999) reported that chopped darawa, sorghum and clover hay were very much preferred over the unchopped material. Chopped clover was eaten as readily as the whole material. The higher intake for chopped material could be because chopping the thicker and tougher stems of these feedstuffs might make it preferable for the animal. However, goats preferred to eat low quality forages (rice straw and wheat straw), in the whole rather than in chopped form. In Paper **II,** chopping the Jackfruit, Flemingia and Acacia foliages resulted in the lowest DMI by goats compared to hanging, tying or stripping methods. This finding contradicts the result of Omokanye *et al.* (2001), who found that the amount of browse consumed by sheep was higher when chopped into pieces of between 2–4-cm long than unchopped material (21 g/kgW$^{0.75}$ *versus* 16 g/kg W$^{0.75}$). In this case, the animals could eat faster when given unchopped browse and they spent more time detaching plant parts from the whole plants. The contradictory results found in these studies could be due to the different characteristics of the browse species with regards to secondary compounds, for example odours that can be released during the chopping process, and also due to the different behaviour of goats and sheep. The goats given chopped Jackfruit, Flemingia and Acacia foliages could have difficulties in selecting different parts of the foliage such as leaves *versus* stems leading to a lower intake.

Wilting or drying Acacia foliage increased the NDF content compared to fresh Acacia. Total tannins of Acacia foliage after wilting or drying were lower than that in fresh Acacia. However, these changes in NDF and tannin contents were not significant. Drying or wilting the *Leucaena leucocephala* foliage reduced the CP content and increased NDF content compared to fresh foliage (Aregheore, 2002). The reason was probably due to reactions, which reduced availability of nutrients during processing. Such reactions might have resulted in changes in the cell wall structures. Parachristous & Nastis (1996) and Aregheore (2002) found that goats preferred the fresh and wilted forms of *Leucaena leucocephala* leaves to the dry forms. The lower intake in dry form compared to fresh form was suggested to be a result of drying increasing NDF and lignin contents of forage thereby resulting in longer rumen retention time, slower rate of passage and consequently reduced voluntary intake of dried leaves. Chemical reactions (*e.g.* Maillard reactions) during the drying process might have rendered the dry leaves bitter and consequently less palatable to the goats relative to the fresh and wilted leaves. Such chemical reactions might have resulted in changes in cell wall structures that could inhibit rumen microbial adhesion and subsequent breakdown of DM in the dry leaves. In this study, kids preferred wilted Acacia foliage to fresh or dried Acacia foliages. It could be that after drying the foliage became very hard, especially the twigs that are often preferred by goats in fresh or wilted forms. After wilting, the foliage became softer and lost some of the distinctive smell of fresh Acacia and contained a lower content of total tannins leading to a higher intake of wilted Acacia by goats. Omakanye *et al.* (2001) found that intake rate was particularly low when sheep were fed dried browse, but not when the browse was fed fresh or wilted.

Effect of method of presentation of foliages on feed intake in goats

Hanging low intake potential foliages as Flemingia or Acacia from the wall of the pen resulted in the highest feed intake by goats, while tying the high intake potential foliage as Jackfruit in the trough resulted in higher intake. According to Meuret (1997), hanging the foliage from the wall of the pen meant a three-dimensional arrangement of feeding material, which enabled the animals to approach the leaves from different angles, leading to higher intake. Hanging the foliages from the wall of the pens was meant to give the animals a condition closer to the natural state when goats browse trees and shrubs. It appears that the goats find it easier to bite and select the leaves from bunches. The green colour of foliages could be a factor stimulating the animals to eat. For Jackfruit foliage, the tying method gave the highest DMI. Jackfruit leaves are very soft and easily removed from the stems. If the Jackfruit foliage was tied above the trough, the leaves stayed in the trough and were consumed, while Jackfruit leaves that fell were left on the floor.

When the foliage species were mixed, all foliages were consumed and goats showed higher daily DMI from mixtures of JF + FM or JF + FM + AC and lower intake from mixtures of JF + AC or FM + AC. In general, goats prefer to alternate between different feeds, but when given opportunity, animals tend to select feeds according to their tastes and preferences, which do not necessarily correspond to the nutritional value of the feed (Abdel-Moneim & Abd-Alla, 1999). Sheep learn to mix their diets in ways that can reduce the potentially harmful effects of toxins, and the availability of nutritious alternatives influences their preferences for toxin-containing foods (Shaw *et al.*, 2006). Animals can better meet their needs for nutrients and regulate their intake of toxins when offered a variety of plants that differ in nutrients and toxins than when constrained to a single plant, even if that is considered the ideal food. Combinations of more shrubs offered to animals promoted greater intake since interactions among flavours, nutrients, and toxins (*e.g.* secondary compounds) lead to enhanced intake (Provenza, 2003). In this study, it was not proved that mixtures result in higher feed intakes. In natural conditions goats consume up to 25 species per day; sheep not more than 12 (Sanon *et al.*, 2006). It is possible that with only one or two species of low intake characteristics, it was not possible to observe this effect.

Effect of including bamboo charcoal in the diet on feed intake and performance in goats

Inclusion of bamboo charcoal in the diet of tannin-rich foliage improved the performance of animals. In this study, the DM, OM, CP digestibility of the diets of goats fed fresh Acacia foliage were highest when bamboo charcoal was added at levels of 0.5 or 1.0 g/kg BW. N retention was significantly higher than that in control and 1.5 g/kg BW in Exp. 1 (Paper **III**) and this was reflected in a higher daily weight gain (Exp.2). The better digestibility and N retention for the diet with bamboo charcoal was probably due to the special properties of charcoal, which can adsorb compounds such as phenols, alkaloids and salicylates and charcoal form complexes with phenolics to prevent hydrosable tannins interfering with enzyme function and protein digestion. It may thereby increase the availability of certain macronutrients, particularly of proteins, leading to a better nutrient condition for the animals. Bamboo charcoal is considered to have a higher adsorption capacity than that wood charcoal because of the special structure of micro pores of the bamboo stems. The surface area of bamboo charcoal was 314.21 m^2/g for carbonized at 800 ^oC in an electric oven and was changed as temperature of the oven changed (Fukuda *et al.*, 2001). The surface area of commercial powdered charcoals made from peat was 720 m^2/g (Cooney & Struhsaker, 1997). Azuma *et al.* (1997) found that the DMI was similar between activated charcoal and Japanese cedar charcoal and the addition of charcoal did not affect the palatability of the diet. N retention in this study was lower in control and 1.5 g/kg BW treatments compared to 0.5 and 1.0 g/kg BW treatments. The reason could be that at the level of 1.5 g charcoal/kg BW some phenolic compounds were adsorbed, but also some other nutrients. A high level of charcoal also meant increased amount of inactive material in the diets, which could have disturbed the rumen metabolism.

Conclusions

- DMI in goat kids and lambs differed for different diets, feedstuffs and levels of feed offered. Both kids and lambs had an ability to consume a diet with higher contents of CP and ash, but lower contents of NDF and ADF. The eating mode was similar for kids and lambs fed WSC as a sole roughage, but the frequency of each eating mode was different. Kids were more aggressive than lambs.

- Total DMI increased linearly with increasing number of animals in the pens, but aggressions were also linearly increased. The daily weight gain and feed conversion ratio were similar for the animals in individual pens and in pens with 5 animals. Kids showed a significantly higher intake in group pens of 5 animals than in single pens, while lambs consumed more in single pens, but these differences in intake did not lead to any difference in weight gain between group sizes within animal species.

- The intake potential by goats was highest in Jackfruit foliage, followed by Flemingia foliage and WSC, and was lowest in Acacia foliage. The eating time and rumination time were longer for higher intake potential foliages.

- WSC chopped into slices (1-3 cm) increased DMI in kids and lambs compared to WSC chopped into 20 cm lengths and split into four parts. Wilting Acacia foliage increased total DMI and DMI of Acacia foliage by goats compared to feeding fresh or dried Acacia foliages, but did not increase growth rate.

- Concentrate added to the diet did not affect the DMI of WSC. DMI of WSC of kids was unchanged as the level of WSC offered increased, while the highest DMI of WSC of lambs was obtained at the level of 6%.

- DMI of goats was highest when foliage species with low intake characteristics such as Flemingia and Acacia were hung on the wall of the pen. Method of presentation appears to be less important for species with high intake characteristics like Jackfruit. Mixing the low feed intake characteristic foliages with Jackfruit increased intake compared to feeding these foliages alone. Mixing the two foliages with low intake potential resulted in higher intake only compared to feeding the foliage with the lowest intake alone.

- The highest DM, OM and CP digestibility and N retention were obtained when bamboo charcoal was added at levels of 0.5 or 1.0 g/kg BW, significantly higher compared to 0 or 1.5 g/kg BW. Kids given a diet with 0.5 g bamboo charcoal/kg BW grew significantly faster than without bamboo charcoal addition. However, DM intake of Acacia and total DM intake were not affected by addition of bamboo charcoal.

Implications

When using individual feeding of sheep and goats, for example in experiments the feed intake is probably below what the animal would consume in farm conditions. If possible two goats and lambs should be kept together and considered as one experimental unit. Farmers often have all animals together in one group and it is possible that the level of aggression is not the same in a group with mixed sexes, but it seems important that in all groups, regardless of size, the space at the fodder trough and the possibility to consume feed is ensured, since most of the aggression takes place in connection to the feeding.

In practice, chopping WSC into slices (1-3cm) increased DMI both in goats and sheep, but for the kids more benefit will be obtained if WSC is offered at a level equal to 4% BW, since the DMI of WSC did not change as the level of WSC offered increased from 4% to 7%. For the lambs, WSC offered at a level of 6% BW gave the highest intake. Both kids and lambs were able to select part of the WSC with higher CP content than the WSC offered. When feeding WSC the CP content of the feed consumed is normally not of any consequence, since WSC has very low CP content and is fed as an energy feed. In a situation of low total CP content in the diet the selection may have some importance, especially if lack of CP is limiting feed intake. The advantage of offering high levels of feed has to be weighed against the costs of the sugar cane, the labour used for chopping and the disposal of the refusals.

The method of hanging the foliages can be practised in all forms both inside and outside the pens. Animals like eating high intake potential foliages such as Jackfruit very much, and often eat it very quickly. One of the special morphological characteristics of Jackfruit is that the leaves are easily stripped off which can result in leaves falling down on the floor, and being rejected by the animals. Jackfruit should be hung or tied above the trough or a net that can collect the fallen leaves, so that animals can eat it later. The hanging method is easy to apply in wooden goat houses and also easily arranged by attaching the foliage to a tree or a fence in the back yard, but for goat houses made of bricks and cement it requires some arrangements to find a good way to hang the foliage.

Mixing low intake potential foliage species with Jackfruit increased feed intake compared to feeding these foliages alone. To reduce the selection of Jackfruit and the refusals of the low intake potential foliage species, the foliage species should be well mixed before feeding.

Charcoal is easy to mix in a commercial concentrate, pelleted and has no effect on the palatability of the concentrate. Bamboo charcoal could be produced from bamboo or bamboo leftovers from house construction or furniture production. It could be carbonized in iron tanks or ceramic jars or even in kilns, but it should be left to cool down completely before being opened to avoid burning the charcoal to ash. If the bamboo is dry the carbonization takes shorter time. The utilization of bamboo charcoal to deactivate the anti-nutritional effect of tannins in Acacia foliages would be easier to apply in a research station or in larger farms, especially if commercial concentrate with the charcoal already added is used. In smallholder situations with a low number of animals using charcoal is probably less interesting since production of bamboo charcoal take time and the charcoal must be mixed with concentrate, which may not normally be used.

Future research

Studies on the effect of group size on the growth rate and the feed intake in goat kids and lambs should be continued to find out the optimal group sizes for each animal species for the growth rate parameter eg. at what group size the intake and aggressive behaviours are balanced to get the best growth rate and feed conversion ratio, and also to identify the tendency for feed intake at higher number of animals per pen (more than five animals).

Behaviour is very important in connection with feed intake and feeding management and the space at the fodder trough and the number of foliage bunches and concentrate troughs play an important role in ensuring that all animals have the possibility to eat at the same time, which is especially important for animals of lower rank. The optimum size and number of feeding places need to be studied. The optimal space allowance and the design of the pen for different animal species and genders should also be studied, since goats are more aggressive than sheep, and males are different from females.

Studies on how to reduce the effect of tannins in protein rich foliage such as Acacia mangium should continue. Cheaper and more easily available substances (eg. clay or supplementation with energy and protein feed to facilitate detoxification processes) need to be found, since using bamboo charcoal is rather complicated on farm level, even if the costs are not high.

Other factors affect the intake potential of a foliage in addition to tannin content. Total tannin content was similar for Jackfruit and Acacia foliage, but DMI was much higher for Jackfruit foliage. Drying Acacia foliage did not improve the DMI and after drying, the essential oils that give this foliage its special smell, were still there. A study should be carried out to define these secondary substances (eg. terpenes) and to find ways to reduce their anti-nutritional effects.

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