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Lindberg J.E., Gonda H.L.

in

Morand-Fehr P. (ed.).
Recent advances in goat research

Zaragoza : CIHEAM
Cahiers Options Méditerranéennes; n. 25

1997
pages 47-58

FIBRE AND PROTEIN DIGESTION IN GOATS

J.E. LINDBERG and H.L. GONDA

Swedish University of Agricultural Sciences,
Department of Animal Nutrition and Management,
Box 7024, S-750 07 Uppsala, Sweden.

SUMMARY

The aim with this review is to present recent data related to the digestion of fibre and protein in goats and discuss comparative data on the digestion of goats and sheep. Although, total tract digestion of organic matter appears to be slightly higher in goats than in sheep, there are no conclusive data showing a superior fibre digestive capacity in goats as compared with sheep. Also, goats and sheep show similar nitrogen digestibility and nitrogen utilization given identical diets at similar levels of intake. There are, however, indications of a more efficient dietary nitrogen utilization in goats fed low protein diets. Goats spend more time eating and less time ruminating than sheep but appears to have a greater efficiency in chewing during eating. No clear species differences in rumen fermentation parameters, rumen retention time and total tract retention time of digesta and liquids in goats and sheep were found. In general, feeding behaviour and diet selection appears to better developed in goats than in sheep, giving goats a higher capacity to adapt to seasonal variations in forage availability under rangeland conditions than sheep.

Key words: fibre, protein, nitrogen utilization, rumen fermentation, diet selection, feeding behaviour, goat, sheep.

INTRODUCTION

Among the domesticated ruminants the goat appears to have a unique ability to adapt to a wide variety of climatic conditions with large variations in available feed resources. Goats survive and are able to reproduce in areas where sheep and cattle cannot and have therefore become important in animal production in temperate areas (Morand-Fehr and Sauvant 1978), in the tropics (Devendra and Burns 1980) and in semi-arid areas (Bhattacharaya 1980; Hadjipanayiotou 1987). The competetiveness of the goat in relation to other domesticated ruminants has lead to several speculations about the scientific reasons for this advantages, one of them being a different digestive efficiency.

A detailed knowledge of the digestion of the two main chemical components in ruminant diets, fibre and protein, is essential for a proper evaluation of the energy and nutritive value of different diets fed to goats. Equally important is that this increases the possibility to make predictions of the production potential in a given area or within a production system with known feed resources. Prediction of limitations in energy and nutrient supply can more easily be made with an extensive knowledge of the digestive capacity of the goat.

The aim with this review is to present recent data related to the digestion of fibre and protein in goats and also, when possible, discuss comparative data on the digestion of goats and sheep in order to identify, if possible, advantages of the goat.

DYNAMICS OF DIGESTION

The digestion process

The digestion of a diet is a complex process including the dynamic interaction between the diet, the animal and the host animal microbial population. In terms of digestion the alimentary tract can be divided into three distinctive parts (i. e. reticulorumen, small intestine, large intestine) all with unique digestive and digesta retention properties. Initially the dietary dry matter has to be reduced in particle size in order to leave the rumen. The digestion in the reticulorumen and the large intestine is characterised by extensive microbial activities from a mixed population of bacteria, protozoa and fungi. Due to repeated mastication of the feed, and the action of rumen microbes, there is a gradual decrease in digesta particle size. The digestion in the small intestine is mainly determined by the activity of endogenous enzymes although the contribution from intestinal bacteria, for certain groups of nutrients, can not be excluded. The amount of available nutrients from a diet is the result of the competition between digestion and digesta passage. The most extensive digestion is obtained when the rate of digesta passage is slow.

Digesta retention

The retention time of digesta in the various sections of the alimentary tract has great influence on the utilization of nutrients in the diet. The retention of digesta in the reticulorumen is important for an efficient digestion of fibre in the diet improving the energy utilization and feed intake. In contrast an excessive rumen digestion of dietary protein can result in poor animal performance and a less efficient utilization of available feed resources.

There appears to be a critical particle size threshold of approximately 1 mm for the passage of feed particles out of the rumen in sheep and goats (Poppi *et al.* 1980) although also other factors such as the functional specific gravity of the feed particle could be of importance (Katoh *et al.* 1988; Murphy and Kennedy 1993). The particle size threshold does not appear to be affected by diet type, diet preparation (milling) or level of intake (Ulyatt 1982).

The digesta can be divided into three components, related to size (liquid, small feed particles, large feed particles), all with different flow properties from the rumen. The liquid component contains liquids, soluble nutrients and small feed particles (<0.2 mm), the small particle component contains feed particles with non-restricted flow from the rumen (0.2-1 mm) due to size and the large particle component contains feed particles with restricted flow from the rumen due to size. The rate of passage for the liquid component of digesta will mainly influence the utilization of soluble carbohydrates and soluble proteins in the diet while the rate of passage of small and large particles will influence the digestion of the cell wall carbohydrates (fibre) and non-soluble proteins in the diet.

There is no clear species difference in rumen retention time (RRT) and total tract retention time (MRT) of digesta and liquids in goats and sheep (Table 1). Udén *et al.* (1982) have shown that the RRT and MRT of liquid was similar in sheep and goats fed grass hay at maintenace level of energy intake. In agreement with this it has also been reported that the RRT of small feed particles was similar in goats and sheep fed at and above maintenance levels of intake (Hadjipanayiotou *et al.* 1988; Hadjipanayiotou and Hadjidemetriou 1990). However, Masson *et al.* (1986) and more recent experiments (Hadjipanayiotou, pers. comm.) suggests that the RRT of small feed particles is significantly shorter in goats as compared with sheep fed identical diets. In contrast Doyle *et al.* (1984) reported a longer RRT of ^{103}Ru-P in goats than in sheep when fed on poor quality diets offered at 30 % above their expected intake. Also Kennedy *et al.* (1992) reported a longer RRT of Cr-labelled milled (1 mm sieve) roughage in goats as compared with sheep fed chopped and pelleted wheaten hay. Huston *et al.* (1986) showed that goats had a shorter RRT of large feed particles (Yb-labelled rumen digesta) and MRT of digesta than sheep grazing native rangeland. Udén (1982) found that the rate of passage of large feed particles (Cr-mordanted fibre) from the rumen and in the total tract was considerably faster in goats as compared with sheep. However, Kennedy *et al.* (1992) found that the MRT of fibre was considerably longer in goats as compared with sheep.

With increasing levels of feed intake RRT of liquid and small feed particles in lactating goats will decrease (Lindberg 1988; Hadjipanayiotou *et al.* 1988; Hadjipanayiotou and Hadjidemetriou 1990). Also, MRT will decrease with increasing feed intake (Lindberg 1988). This is a function of the increasing feed intake *per se* as it has been shown that lactating goats fed at similar levels of intake as dry goats showed no differences in RRT (Hadjipanayiotou *et al.* 1988).

Varying the roughage to concentrate ratio in diets in dry and lactating goats did not significantly affect the RRT of small feed particles (Hadjipanayiotou and Hadjidemetriou 1990). However, Santini *et al.* (1992) reported that the RRT of liquid and the transit time of hay through the hindgut decreased with increasing fiber intake.

Feed particle size reduction

The initial chewing during eating and the further chewing during rumination are the two processes affecting the breakdown of feed particles in ruminants. In sheep the particle size reduction appears to be very rapid after feeding (Moseley and Jones 1984) and it has been estimated that approximately 50% of the feed dry matter could be expected to be reduced to less than 1 mm in size during the first episode of chewing during eating (Ulyatt 1982).

There are several reports showing that goats spend more time eating and less total time ruminating than sheep (Focant *et al.* 1986; Domingue *et al.* 1991a; McSweeney and Kennedy 1992). Also expressed per unit feed intake goats fed *ad lib.* spent less time ruminating than sheep (Focant *et al.* 1986; Domingue *et al.* 1991a; McSweeney and Kennedy, 1992).

Despite a shorter total rumination time in goats they showed a greater efficiency than sheep in chewing during eating resulting in a more extensive breaking down of feed particles to less than 1.0 mm in size (Domingue *et al.* 1991a). Also Kennedy *et al.* (1992) showed that goats had a more extensive particle size reduction than sheep resulting in a rumen digesta with a lower frequency of feed particles above 1.18 mm in size and a smaller mean particle size of the digesta.

RUMEN FERMENTATION

Due to the activity of the rumen microorganisms the various components of the diet are gradually degraded in the reticulorumen with the production of microbial mass, fermentation gases, ammonia and volatile fatty acids (VFA). The extent of fibre and protein digestion in the reticulorumen is determined by the chemical composition of the plant material, physical properties of the plant, feed processing conditions, rumen microbial activity and the time available for microbial digestion.

A compilation of rumen fermentation data in different diets fed to goats and sheep is given in Table 2. Rumen fermentation pattern (pH, ammonia, total VFA, molar proportions of VFA) was similar in goats and sheep fed different roughages alone or together (1:1 ratio) with concentrate (Hadjipanayiotou and Antoniou 1983; Antoniou and Hadjipanayiotou 1985). Also in goats and sheep grazing on semiarid pasture, unsupplemented or supplemented with barley (barley alone or barley with 1% urea), García *et al.* (1994) found no between species differences in rumen pH and rumen fermentation pattern. The small supplement of barley [88 g dry matter (DM)/d] did not affect rumen pH and rumen fermentation in either species (García *et al.* 1994). However, when fed a low-quality diet (mature prairie grass; Domingue *et al.* 1991b) goats were reported to have slightly lower proportions of rumen propionate, higher proportions of valerate, higher ammonia concentration and lower rumen pH than sheep. Also, Alrahmoun *et al.* (1986) reported higher ammonia and VFA levels in the rumen of goats than in sheep fed on treated straw alone or supplemented with soyabean meal. In contrast, Isac *et al.* (1994) found significantly higher rumen ammonia and VFA levels in sheep than in goats fed lucerne hay and vetch hay at maintenance. In goats and sheep fed diets with varying proportions of artificially dried ryegrass, wheat straw and concentrate the rumen VFA levels were higher and rumen pH was lower in sheep than in goats (Flachowsky and Tiroke 1993).

The dietary composition has a marked influence on rumen pH and rumen fermentation pattern (Hadjipanayiotou and Antoniou 1983; Antoniou and Hadjipanayiotou 1985; Giger *et al.* 1988). In particular diet carbohydrate quality and hence susceptibility to rumen digestion can have a significant effect (Giger *et al.* 1988). With a change in diet composition from a low to a high fibre content rumen pH and molar proportions of acetate should be expected to increase. In agreement with this García *et al.* (1994) found a significant linear relationship between the fibre content of the diet consumed and the acetate: propionate ratio in rumen liquid. The latter effect was similar in both goats and sheep.

FIBRE DIGESTION

The utilization and hence the nutritive value of the dietary carbohydrates in goats appears to be firstly determined by the soluble cell content and secondly by the cell wall content (Giger *et al.* 1986). While the soluble cell content of compound feeds is rapidly and almost completely digested in the rumen the digestion of the cell wall fraction is more variable and often incomplete (Giger *et al.* 1987). The selection of feedstuffs on the basis of carbohydrate composition therefore becomes very important in order to meet both a high total tract digestibility and a suitable rumen digestion pattern (Giger *et al.* 1987). The variation in total tract cell wall digestibility is large and appears primarely related to the degree of cell wall lignification (Giger *et al.* 1986). A decrease in the rumen degradation of structural carbohydrates in roughage and concentrate can be expected when the level of concentrate is increasing in the basal diet (Archimède *et al.* 1995a). When the dietary proportion of concentrate increases in the diet of dry goats there appears to be a decrease in the cellulolytic activity in the rumen despite a very weak relation between changes in rumen pH and cellulolytic activity (Archimède *et al.* 1995c).

The organic matter digestibility (OMD) of compound feeds appears to be strongly correlated to the fibre [crude fibre, acid detergent fiber (ADF), neutral detergent fiber (NDF)] and lignin content of the feed (Giger-Reverdin *et al.* 1992, 1994). The best predictor seems to be acid detergent lignin (ADL: Giger-Reverdin *et al.* 1992, 1994) with no additional benefit of using NDF, ADF and ADL together (Giger-Reverdin *et al.* 1992). However, when compiling more extensive data including several european laboratories it was obvious that a significant improvement in the accuracy of predicting OMD was obtained when NDF, ADF and ADL were considered simultaneously (Giger-Reverdin *et al.* 1994). As there appears to be no interactions with the feed content of crude protein (16.3-33.3% CP) and ether extracts (1.2-6.8% EE) or with the level of feed intake, the data could be extrapolated also to more extensive production systems (Giger-Reverdin *et al.* 1992). The prediction of energy content of compound feeds can be made with good precision using the dietary content of CP and EE in combination with ADL alone or with NDF, ADF and ADL together (Giger-Reverdin *et al.* 1994).

Goats have been considered to be superior to sheep in digesting fibre rich diets (Devendra and Burns 1980; Gihad *et al.* 1980). In accordance with this, Al Jassim *et al.* (1991) found significantly higher digestibility of NDF and ADF in desert goats than in Assawi lambs fed a molasses-NaOH treated wheat straw diet. There are, however, several recent reports indicating no species differences in fibre digesting capacity between goats and sheep.

Despite differences in rumen fermentation patterns between goats and sheep no significant differences in the rate of *in sacco* digestion of DM, fibre and protein in lucerne hay and vetch hay were reported (Isac *et al.* 1994). Also Flachowsky and Tiroke (1993) found similar extent and rate of *in sacco* digestion of DM in artificially dried ryegrass, wheat straw and concentrate in goats and sheep fed varying proportions of artificially dried ryegrass, wheat straw and concentrate. Huston *et al.* (1986) reported a lower *in vitro* digestion of DM with rumen inoculum from goats than from sheep.

In an extensive recent review of comparative digestion in goat and sheep Tolkamp and Brouwer (1993) found no effect of species in OMD differences in diets with varying fibre content. Some examples of reported digestibility values in goats and sheep are given in Table 3. Total tract digestion of fibre in temperate grass was not different in sheep and goats fed at maintenance level of energy intake (Udén and Van Soest 1982). Goats and sheep given chopped and pelleted wheaten hay *ad lib.* alone or as a mixture had similar total tract digestion of DM (Kennedy *et al.* 1992). Also goat and sheep fed lucerne hay and vetch hay at maintenance had similar total tract digestion of DM, protein, fibre and energy (Isac *et al.* 1994). However, Alrahmoun *et al.* (1986) and Domingue *et al.* (1991b) reported that in spite of a higher DM intake, goats had higher rumen degradation rate of cell wall carbohydrates than sheep when fed low quality (low-protein, high-fibre) diets.

When comparing most published comparative work on digestion in goat and sheep Tolkamp and Brouwer (1993) found goats to be superior to sheep in total tract OM digestion. It should be noted, however, that the difference between species was very small (+ 0.8% units for goats). An interesting observation was the indication of a superiority of goats to digest the dietary OM when the CP content of the diet was below 100 g CP per kg, while no CP effect was seen at a dietary CP content above 100 g CP per kg diet (Tolkamp and Brouwer 1993).

PROTEIN DIGESTION

In lactating goats (Giger-Reverdin *et al.* 1991a) the largest loss of ingested dietary nitrogen is through the urine (43%), followed by fecal losses (29%) and through excretion with milk nitrogen (24%). With increasing intake of dietary nitrogen the losses of nitrogen could be expected to increase (Badamana *et al.* 1990; Badamana and Sutton 1992). The largest increase in nitrogen losses with increasing intake of dietary nitrogen could be expected in the urine with less pronounced losses in the feces (Badamana *et al.* 1990; Badamana and Sutton 1992). As shown by Giger-Reverdin *et al.* (1991) urinary nitrogen losses are, in addition to nitrogen intake, influenced by the balance between rumen degradable nitrogen and fermentable energy (dietary protein quality in relation to available dietary energy), the carbohydrate intake and the dietary lignin content (indirectly an indicator of energy content; see Giger-Reverdin *et al.* 1994). Fecal nitrogen losses are in addition to nitrogen intake influenced by the intake of structural carbohydrates, lignin intake and the dietary balance between rumen degradable nitrogen and fermentable energy (Giger-Reverdin *et al.* 1991a). An increase in structural carbohydrates and lignin increases fecal nitrogen losses.

Reported data on dietary effects on rumen ammonia levels in goat and sheep are inconsistent (Table 2). Hadjipanayiotou and Antoniou (1983) and García *et al.* (1994) found no species differences in rumen ammonia levels in goat and sheep on a wide range of diets. In contrast, Isac *et al.* (1994) consistently found higher rumen ammonia levels in sheep than in goats fed medium quality hay at maintenance level of intake. Antoniou and Hadjipanayiotou (1985) found significantly higher rumen ammonia levels in sheep fed lucerne hay alone and significantly lower levels in sheep fed acacia alone and acacia plus concentrate. In contrast, when goats and sheep were fed a prairie grass straw diet ad libitum (Domingue *et al.* 1991b), the rumen ammonia concentration was found to be greater in goats than in sheep, in correlation to a higher N intake and a lower water intake.

In addition to rumen ammonia, recycled urea constitutes an important source of nitrogen for the rumen microbial population. It has been estimated that at least 70% of the nitrogen ingested daily passes through the urea pool of the body (Harmeyer and Martens 1980). The major determinant of the urea synthesis is the daily nitrogen intake while the source of ingested nitrogen and the site of absorption from the gastrointestinal tract appears to be of minor importance. According to Harmeyer and Martens (1980) there appears to be no species differences in urea metabolism between goats and sheep. In contrast Domingue *et al.* (1991b) calculated that goats had higher values for nitrogen recycled to the rumen via saliva. Greater salivary secretion rates in goats than in sheep have been reported by Seth *et al.* (1976) and Domingue *et al.* (1991a).

The rumen degradability of CP in fishmeal (Hadjipanayiotou *et al.* 1988), soya bean meal (Hadjipanayiotou *et al.* 1988) and lucerne hay (Isac *et al.* 1994) was similar in goats and sheep. In contrast the CP *in sacco* degradability of vetch hay was lower in goats than in sheep. The reported between species differences in rumen feed protein degradability could most likely be explained by differences in rumen microbial activities as there appears to be no consistent species differences in rumen outflow rate of feed proteins (Hadjipanayiotou *et al.* 1988; Hadjipanayiotou and Hadjidemetriou 1990).

In contrast to sheep there are limited information on the efficiency of microbial protein synthesis in goats. It can be calculated from the data of Ash and Norton (1987), using ^{35}S-labelled cysteine as microbial marker, that the efficiency of microbial crude protein production in Australian cashmere goats was 170 g CP/kg total tract DOM in a low protein diet and 182 g CP/kg total tract DOM in a high protein diet. Assuming a conversion factor of 0.04 between microbial RNA nitrogen and urinary excretion of allantoin nitrogen in goats (Lindberg, 1991) and a content of 113 g RNA nitrogen/kg microbial nitrogen (Storm and Ørskov 1983) an estimate of the efficiency of microbial crude protein production of 175 g CP/kg total tract DOM can be calculated from data on dairy goats (Lindberg, 1985). From a recent paper by Archimède *et al.* (1995c) a microbial crude protein production of 144 g CP/kg total tract DOM can be calculated assuming that 70% of the total tract digestion of OM occured in the rumen (Archimède *et al.* 1995b). These estimates are in the same range as those found in sheep.

With regard to nitrogen digestibility (ND) and capacity to retain nitrogen (NR) there is a lack of consistency on between species differences (Table 4). In a recent paper Nuñez-Hernandez *et al.* (1991) reported that goats had greater ND and similar NR as sheep fed on mountain mahogany (8% CP on DM basis). In contrast, ND and NR were found to be lower in goats than in sheep when fed on treated wheat straw and molasses diets supplemented or unsupplemented with rumen undegradable protein (12-16% CP on DM basis) (Al Jassim *et al.* 1991). Additional references on CP digestibility in goats and sheep can be found in the review by Brown and Johnson (1984).

It was estimated that 60-64% of the non ammonia nitrogen (NAN) coming from the rumen of goats and sheep fed a forage diet was digestible in the small intestine, while 23-30% of the nitrogen disappeared in the hindgut (Alam *et al.* 1987).

PARTITION OF DIGESTION

Of the total tract DM digestion of high quality meadow hay 60% occured in the rumen, 29% in the small intestine and 13% in the large intestine (Alam *et al.* 1987). Archimède *et al.* (1995b) found that on average 70% of the total tract OM digestion occured in the rumen. A major part of the fiber digestion (approximately 94% of the NDF digestion) occured in the rumen (Alam *et al.* 1987) while only minor effects on the fiber digestion could be expected in the omasum (Holtenius and Björnhag 1989). Also in the work by Archimède *et al.* (1995b) on average 90-95% of the cellulose digestion was found in the rumen. With increasing levels of intake a decrease in the proportion of OM and NDF digestion taking place in the rumen should be expected (Alam *et al.* 1987). While there were indications of increasing hindgut digestion of OM and NDF with increasing feed intake the proportion of OM digested in the small intestine was unaffected.

There appears to be no differences between goats and sheep in the digestion of DM, fiber and non ammonia nitrogen (NAN) at any site of the digestive tract (Alam *et al.* 1987).

ASSOCIATIVE EFFECTS

There are significant associative effects between diet composition and the digestion of cell walls in goats (Giger-Reverdin *et al.* 1991b). An associative effect was seen up to 24 h rumen incubation *in sacco* where the cell wall of incubated samples (lucerne hay and compound feeds) were less degraded on the diets with highest levels of concentrate inclusion (50% of DM), while at 48 h rumen incubation no differences between diets were seen (Giger-Reverdin *et al.* 1991b). The highest cell wall degradation was found in the diet with the lowest proportion of a starch rich concentrate (15% of DM) and the lowest cell wall degradation was found in the diet with a fibre rich concentrate (50% fibre rich concentrate). These results suggest that the balance between slowly and rapidly rumen digestible carbohydrates (sugar, starch, fiber) in the diet of goats is an important factor for the digestive efficiency of plant cell walls.

ANTINUTRITIONAL FACTORS

The potential digestion of fibre and protein can be influenced by anti-nutritional factors in the diet. Tannins are the most common anti-nutritional factor in plants and can be found in herbs, shrubs and leaves. Due to the ability to form complexes with proteins, tannins can bind to feed proteins and also inhibit endogenous and microbial enzymes. The addition of polyethylene glycol (PEG) to the diet can markedly reduce the negative effect of tannins on digestion (Silanikove *et al.* 1994). This is due to the ability of PEG to form irreversible complexes with tannins over a range of pH with a higher affinity of tannins to form complexes with PEG than with protein.

Nuñez-Hernandez *et al.* (1991) found higher rumen VFA and ammonia levels with PEG supplementation in goats and sheep fed diets with mountain mahogany leaves but found no improvement in the digestion of fibre and protein. In contrast, marked improvements in the digestion of fibre and protein, as well as in feed intake, has been found in both goats and sheep given PEG in addition to tannin rich diets (Silanikove *et al.* 1994; Silanikove, pers. comm.; Decandia *et al.* 1995). It has been shown that once-a-day provision of PEG is sufficient to obtain a positive effect both on digestion and feed intake of the same magnitude as twice daily provision (Silanikove *et al.* 1994; Silanikove, pers. comm.). The response to PEG supplementation appears to be much better in goats than in sheep with goats needing only approximately one fifth of the PEG dose required for sheep (Silanikove *et al.* 1994; Silanikove, pers. comm.).

WITHIN SPECIES DIFFERENCES IN DIGESTION

When comparing Nubian, Alpine and Angora goats on diets with increasing CP content (8, 14 and 20% CP) no breed differences could be measured in nitrogen utilization, rumen fermentation (pH, VFA, ammonia), plasma metabolites and total tract digestibility of DM, NDF, CP and energy (Sahlu *et al.* 1993). In contrast Choshniak *et al.* (1984) reported significantly higher energy digestibility of alfalfa hay and wheat straw in wild goats (Nubian ibex) and desert Bedouin goats than in Swiss Saanen goats, and Silanikove (1986) reported significantly higher DM, fiber and nitrogen digestibility of alfalfa hay, a mixture of Rhodes grass and alfalfa hay and wheat straw in desert Bedouin goats than in Swiss Saanen goats. Recently Silanikove *et al.* (1993) reported a significantly higher DM digestibility in desert Bedouin goats as compared with Swiss Saanen goats (68 vs. 61%) fed a Rhodes grass and alfalfa diet (90:10) *ad lib.* and a slower rate of digesta and fluid passage from the rumen from the desert Bedouin goats. The desert Bedouin goats also had a significantly higher rumen VFA concentration (+13%), rumen VFA production rate (+20%) and VFA absorption rate from the rumen (+36%) as compared with Swiss Saanen goats. Despite higher VFA production and VFA concentration the average rumen pH remained higher in desert Bedouin goats (6.2 vs. 5.9) than in Swiss Saanen goats (Silanikove *et al.* 1993).

FEEDING BEHAVIOUR AND DIET SELECTION

Goats differ from sheep in their feeding behaviour. One important feature of the goat is its unique grazing behaviour and the well developed selective feeding behaviour (Lu 1988; Narjisse 1991). While sheep are almost exclusively grasers (Lu 1988) goats are neither exclusively grasers nor exclusively browsers (Lu 1988; Fedele *et al.* 1993).
It appears as if goats have a better developed capacity to select the more nutritious parts of the forage offered as compared with sheep and to adapt to seasonal variations in forage availability (Lu 1988). This becomes most evident when goats are offered shrubs and trees on rangeland when the available forage quality often is low and variable (Meuret *et al.* 1991) but is less evident when the feed is given in a through (Morand-Fehr *et al.* 1991). When allowed a free choice of a large variety of herbages (grasses and forbs) goats try to balance variations in fibre content in available pasture vegetation, both at high and low fibre content, and also to maintain a protein content in the ingested herbage within a limited range (Fedele *et al.* 1993). An interesting observation in the work by Fedele *et al.* (1993) was the breed differences in the behaviour of selecting plants which implies that the imprinting of the goat is an important feature for the feeding behavior.

The selective feeding behaviour of the goat improves dry matter intake, diet nutrient balance and thereby also the potential production. It is important to emphasise that the selective feeding behaviour of goats can have a marked influence on the dynamics of digestion, digestibility and nutrient utilization of a diet and should therefore be considered when species comparisons on different diets are being made.

CONCLUSIONS

In general total tract digestion of organic matter appears to be slightly higher (less than 1 digestibility unit) in goats than in sheep. There are, however, no conclusive data showing a superior fibre digestive capacity in goats as compared with sheep. In general goats and sheep show similar nitrogen digestibility and nitrogen utilization given identical diets at similar levels of intake. There are, however, indications of a more efficient dietary nitrogen utilization in goats fed low protein diets.

Goats spend more time eating and less time ruminating than sheep but appears to have a greater efficiency in chewing during eating. This results in a more extensive breaking down of feed particles below the critical particle size threshold (less than 1 mm) for passage out of the rumen in goats as compared with sheep. There are, however, no clear species differences in rumen retention time and total tract retention time of digesta and liquids in goats and sheep. Also there appears to be minor differences in rumen fermentation parameters between goats and sheep fed identical diets at similar levels of intake.

In general feeding behaviour and diet selection appears to better developed in goats than in sheep. This gives goats a higher capacity to adapt to seasonal variations in forage availability under rangeland conditions than sheep. This ability could also affect the utilization of a diet when selection is allowed and make between species comparisons of digestion difficult.

It should be noted that there are reports of important within species differences in feeding behaviour and diet selection as well as in digestibility, rumen passage and rumen fermentation. These within species differences becomes important under rangeland conditions with a scarcity of available roughage for grazing. This area requires more research and the knowledge obtained could be useful when selecting animals suitable for different production systems.

ACKNOWLEDGEMENTS

We express our sincere thanks to collegues in the FAO-CIHEAM Subnetwork for sheep and goat nutrition for invaluable assistance in providing published and unpublished data on goat nutrition.

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Table 1. Retention time (h) of digesta and liquid in the rumen (RRT) and the total tract (MRT) in goats and sheep fed various diets.

Diet	Species	Intake (g/kgBW)	Digesta		Liquid		Reference
			RRT	MRT	RRT	MRT	
Timothy hay	Goats	24	27	41	19	26	Udén et al. (1982)
	Sheep	22	37	57	19	28	
Straw+concen. (1:1)	Goats	15	17	-	-	-	Hadjipanayiotou et al. (1988)
	Sheep	15	18	-	-	-	
Hay+concen. (1:1)	Goats	45	12	-	-	-	Hadjipanayiotou et al. (1988)
	Sheep	46	12	-	-	-	
Wheaten hay	Goats	23	22	51	-	-	Kennedy et al. (1992)
	Sheep	30	19	44	-	-	
Lucerne hay*	Goats	46	34	-	-	-	Isac et al. (1994)
	Sheep	42	36	-	-	-	
Vetch hay*	Goats	43	31	-	-	-	Isac et al. (1994)
	Sheep	40	37	-	-	-	

* Intake in g/kg $W^{0.75}$.

Table 2. Rumen pH, ammonia (NH_3-N; mmol/l), total volatile fatty acids (VFA; mmol/l) and molar proportions (%) of acetate (Ac), propionate (Pr) and butyrate (Bu) in goats and sheep fed roughage alone or roughage plus concentrate.

Diet	Species	pH	NH_3-N	VFA	Ac	Pr	Bu	Ref*
Barley hay (BH)	Goats	6.8	4.3	54	73	18	8	(1)
	Sheep	7.0	5.9	75	75	17	8	
BH+concentrate	Goats	6.2	8.2	83	67	19	13	(1)
	Sheep	6.6	6.3	80	67	19	14	
Lucerne hay (LH)	Goats	6.7	16.0	102	80	15	6	(1)
	Sheep	6.9	16.5	106	78	16	6	
LH+concentrate	Goats	5.8	16.8	135	59	28	12	(1)
	Sheep	5.8	14.6	115	68	20	15	
Barley straw (BS)	Goats	7.2	4.3	28	74	17	8	(1)
	Sheep	7.4	2.6	30	76	18	7	
BS+concentrate	Goats	6.5	6.1	74	68	21	12	(1)
	Sheep	6.4	6.3	82	70	20	10	
Acacia (A)	Goats	6.8	3.8	54	72	21	7	(1)
	Sheep	6.9	4.1	58	74	20	6	
A+concentrate	Goats	6.4	8.4	95	67	12	16	(1)
	Sheep	6.2	11.6	101	70	18	12	
Treated straw (TS)	Goats	6.4	7.4	61	72	22	5	(2)
	Sheep	7.1	0.5	27	67	28	5	
TS+urea	Goats	6.6	4.8	85	75	19	4	(2)
	Sheep	7.0	4.5	59	73	20	6	
TS+soybean meal	Goats	6.4	4.1	97	73	18	5	(2)
	Sheep	6.6	1.4	73	72	20	6	
Praire grass straw	Goats	6.7	8.2	96	71	19	6	(3)
	Sheep	6.9	5.7	87	71	20	6	
Lucerne hay	Goats	6.7	7.0	82	74	16	7	(4)
	Sheep	6.8	9.6	117	73	17	7	
Vetch straw	Goats	6.9	3.8	81	74	16	8	(4)
	Sheep	6.8	4.4	112	72	18	8	

* References: 1. Hadjipanayiotou & Antoniou, 1983; 2. Alrahmoun et al., 1986; 3. Domingue et al., 1991b; 4. Isac et al., 1994.

Table 3. Total tract digestibility (%) of dry matter (DM), crude fibre (CF) and plant cell walls (CW) in various roughages fed to goats and sheep.

Diet	Species	DM	CF	CW	Reference
Timothy hay	Goats	49	-	44	Udén et al. (1982)
	Sheep	48	-	44	
Barley hay	Goats	55	54	-	Antoniou et al. (1985)
	Sheep	56	53	-	
Lucerne hay	Goats	66	51	-	Antoniou et al. (1985)
	Sheep	67	56	-	
Acacia	Goats	48	34	-	Antoniou et al. (1985)
	Sheep	47	35	-	
Sudex hay	Goats	60	64	-	Antoniou et al. (1985)
	Sheep	61	64	-	
Barley straw	Goats	48	57	-	Antoniou et al. (1985)
	Sheep	44	53	-	
Lucerne hay	Goats	55	-	30	Isac et al. (1994)
	Sheep	56	-	33	
Vetch straw	Goats	58	-	53	Isac et al. (1994)
	Sheep	55	-	53	

Table 4. Dietary crude protein content (% of dry matter), apparent total tract digestibility of nitrogen (%; N dig.) and nitrogen retention as a proportion (%) of the nitrogen intake (N ret/N int) in various diets fed to goats and sheep.

Diet	CP %	Species	N dig.	N ret/N int	Reference
Natural grass *(Hypparrhenia spp.)*	7	Goats Sheep	43.4 44.2	-25 -26	Gihad (1976)
Tree leaves *(P. cineraria)*	14	Goats Sheep	38.9 22.0	42 13	Bohra (1980)
Pasture hay *(T. subterraneum)*	19	Goats Sheep	67.3 66.6	14 17	Doyle et al. (1984)
Pasture hay *(L. rigidum)*	5	Goats Sheep	28.5 18.9	-7 -14	Doyle et al. (1984)
Pasture hay *(T.sub. + L.rig.)*	7	Goats Sheep	27.6 28.3	-5 -29	Doyle et al. (1984)
Barley hay	10	Goats Sheep	55.7 58.8	12 17	Antoniou et al. (1985)
Lucerne hay	23	Goats Sheep	76.4 78.2	14 17	Antoniou et al. (1985)
Acacia	14	Goats Sheep	29.5 36.2	-40 -20	Antoniou et al. (1985)
Sudax hay	9	Goats Sheep	55.9 59.5	3 9	Antoniou et al. (1985)
Barley straw	5	Goats Sheep	18.9 19.3	-57 -51	Antoniou et al. (1985)
Grass straw *(B. catharticus)*	9	Goats Sheep	30.5 28.2	-19 -11	Domingue et al. (1991b)
Lucerne hay	18	Goats Sheep	70 73	15 16	Isac et al. (1994)
Vetch straw	8	Goats Sheep	50 46	2 10	Isac et al. (1994)