9
Ingestive Behavior, Diet Selection, and Feed Intake

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KEY TERMS

Grazing—consumption of herbaceous material from the plant biomass.
Browsing—consumption of more lignified material from the plant biomass, often above head height.
Ingestive behavior—the behavioral components that result in the animal selecting and consuming forage.
Diet selection—the process of choosing which plant parts and species are consumed.
Diet composition—the consequence of diet selection; the composition of the diet in terms of plant parts/species.
Intake—the amount of forage consumed; "voluntary intake" is the amount of a given diet consumed voluntarily by the animal when the amount available is nonlimiting.
Bipedal foraging—foraging above the normal reach by browsing while on the hind legs.
Buccal architecture/dentition—the morphology of the jaw, mouth, and teeth/the condition of the teeth, especially incisor teeth.
Condensed tannins—a major class of plant secondary compounds, capable of complexing dietary and gut proteins.
Tannin-binding salivary proteins (TBSP)—salivary proteins that complex with dietary tannins, thus reducing their effect on dietary proteins; proline-rich salivary proteins (PRP) are a specialized subset of TBSP.

OBJECTIVES

By completing this chapter, the reader will acquire knowledge on:

- The balance of browsing versus grazing is different in goats compared with other domestic ruminants.
- The browsing process in goats is only partly "driven" by bipedal grazing.
- That as a consequence, goats will select different plant species than sheep or cattle, when confronted with the same biomass.
- That within goats, diet selection will be affected by age, sex, buccal architecture/dentition, and physiological state.
- Analyzing the validity of statements about dietary preferences and diet selection in goats.
- That the evidence suggesting that goats digest forage better than sheep, or that they eat more of a given forage than sheep, is not conclusive.
- The importance of dietary condensed tannins as one component of the diet selection process.
- How to synthesize this knowledge into a comparative understanding of the processes of diet selection and intake in goats, compared with other domestic herbivores.

INTRODUCTION

Goats have the ability to use browse as well as the herbaceous components of the forage resource, and can provide animal products from rangeland or semiarid environments that would not suit sheep and cattle. Goats thus assume major economic importance in less-favored environments, often in the world's less developed economies.

The interaction of foraging goats with the plant biomass involves components relating to the animals themselves, the plant resource available to them, and the extent to which the system of livestock management permits the processes of diet selection and intake to proceed. Ingestive (eating) behavior, diet selection, forage intake, and animal production are components of a continuum of mechanisms linking plant resource and animal product.

EATING BEHAVIOR AND DIET SELECTION

Free-ranging livestock, including the goat, usually select a diet that differs in botanical composition and in quality from the average of the available feed. However, the demonstration that the diet composition differs from the plant biomass does nothing to elucidate why this is so or why certain plants were selected or rejected. The fact that goats often select a diet higher in browse species than would be selected by sheep or especially cattle tells us little about why more herbaceous components of the plant biomass were not selected. Therefore, caution is required in interpreting diet selection data.

Some of the factors influencing feeding behavior and diet selection in grazing ruminants are listed in Table 9.1, and in part have also been discussed elsewhere (AFRC, 1998; NRC, 2007; Animut and Goetsch, 2008). Examination of the information in Table 9.1 leads to two closely related conclusions. First, the process of diet selection is exceedingly "multifactorial." Second, a number of the listed factors are closely related (for example, season and the species composition of the plant biomass, or age of goat and the state of their dentition). A degree of confounding between the factors is thus not only possible but highly likely. Unfortunately, studies of diet selection in goats have not always paid sufficient attention to this.

Table 9.1 Indicative summary of some of the factors shown to influence ingestive behavior and diet selection in goats.

Factor
1. Species composition of the biomass/ season of year
2. Clover content of and clover position in the "sward"
3. "Presentation" of the biomass—zero grazing versus grazing; species in rows cf. mixed sward; species offered separately or together
4. Sward height, biomass; stocking rate
5. Condensed tannin content of species on offer
6. Dry matter content of the forage
7. Odor/flavor of the forage
8. Previous experience and adaptation of grazing animals; species of animal that grazed biomass previously
9. Differences in possible instantaneous intake rate between biomass components
10. Breed, gender, age, and physiological state of goats
11. Buccal architecture and integrity of teeth
12. Goats grazing separately or co-grazing with other species
13. Grazing height, bipedal versus quadripedal foraging

General Observations on Diet Selection by Goats

Frequently, ruminant livestock have been classified as being grazers (grass/forb consumers), as concentrate selectors/browsers, or as intermediate or mixed feeders. Sheep and especially cattle are regarded as grazers, with relatively broad muzzles and a cornified tongue tip designed for grass consumption at low biomass. Goats, on the other hand, have a narrow mouth and mobile lips and tongue that should allow selective browsing, and are regarded as "intermediate feeders" (see NRC, 2007; Animut and Goetsch, 2008). The evidence from many published studies indicates conclusively that when faced with a mixture of browse, forbs, and grasses, goats will select a diet containing much more browse than would be selected by sheep or especially cattle. In a Mediterranean shrubland, Papachristou (1994) reported that goats took 40–60% of their bites from browse species. However, when the availability of the herbaceous component was high, it could make up >50% of the diet (Papachristou, 1994). By contrast, in an oak forest environment, cattle co-grazing with goats took more than 97% of their bites from the herbaceous component of the biomass. In a more recent comparison in the Sahelian region of Africa, Sanon et al. (2007) reported that cattle spent 4.5–6.6% of their time browsing, depending on season. By contrast, goats browsed for 43–52% of their time; sheep were intermediate at 4.8–28% of their time. A feature of many published studies is that diet selection is measured indirectly in terms of ingestive behaviors or features of the plant biomass. It can be difficult to convert plant biomass data, or data about percentages of times spent grazing different plant components, to actual intakes of those components (Dove and

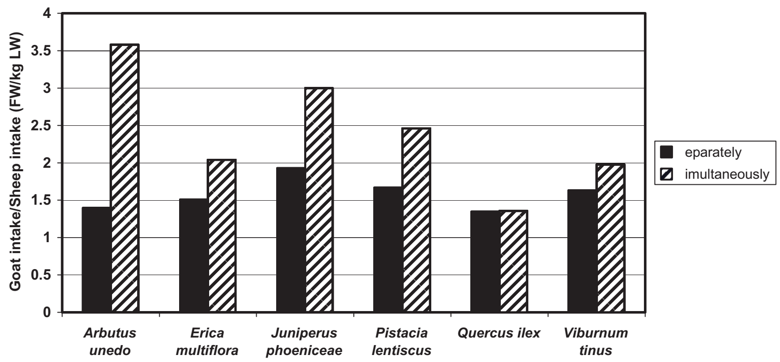

Figure 9.1 Effect of feeding a range of browse species, either separately or simultaneously, on the relative intake of goats versus sheep (recalculated from the data of Rogosic et al., 2006a).

Mayes, 2005). A recent study in Spain (Celaya et al., 2007) avoided such problems in co-grazing cows, ewes, and does in heathland in Spain, by estimating diet selection directly, using plant wax alkanes as markers (see Dove and Mayes, 2005). Their data confirm behavioral observations. The herbaceous component made up 75–90% of the intake of cows whereas in ewes, shrubs made up 36–59% of the diet, and in does, 49–85% of the diet. There is thus little doubt that, where diet choice is possible, goats will consume more browse than sheep and particularly, more than cattle.

Factors Influencing Diet Selection

Season of Year and Species Composition of the Plant Biomass

In many studies, selection of particular plant species in the diet has been, in part at least, a function of the seasonal availability of different species. As would be expected, the species composition of the biomass, both in its own right and as influenced by season, has a marked effect on diet selection by the goat. The preference of goats for particular plant species also depends on whether different plants are fed together or separately. For example, Rogosic et al. (2006a) offered six different browse species to either housed goats or housed sheep. When the shrubs were offered individually, goats always ate more than sheep. Recalculation of their data indicates that the ratio of goat : sheep intakes (both expressed as g DM/kg LW) ranged from 1.35–1.93 across the different plant species (Figure 9.1). When all six plant species were offered simultaneously to the two species of animals, goats again always ate more than sheep, but the intake ratios ranged from 1.36–3.58 between plant species. In other words, the preference for different plant species was more extreme when all plant species were offered together. This means that caution is required when extending indoor data obtained by feeding individual plant species to field situations where a range of plant species is on offer at the same time.

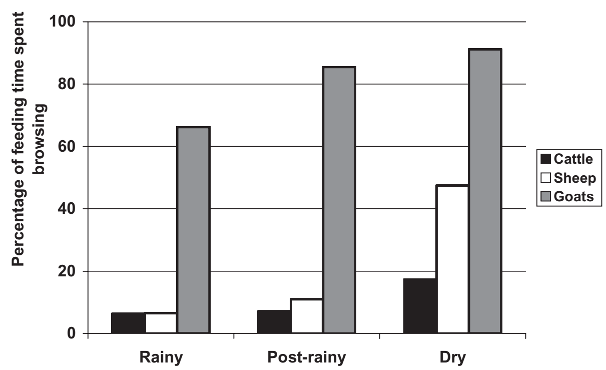

Figure 9.2 Comparison of the time spent browsing by cattle, sheep, and goats in a natural pasture in the Sahelian region of Africa (recalculated from the data of Sanon et al., 2007).

Marked seasonal effects on diet composition have been reported in many studies. For example, Sanon et al. (2007) reported data for goats, sheep, and cattle grazing natural pasture in the Sahelian region of Africa. Their data for the time spent browsing have been recalculated as a percentage of the total feeding time; differences between animal species and seasons are shown in Figure 9.2. As the seasons progressed, there was little change in the time cattle spent browsing, despite the progressive loss of the herbaceous component of the plant biomass. The apparent increase in browsing by cattle in the dry season was due more to a reduction in their time spent feeding (from 72–38% of the day), rather than an actual increase in the time spent browsing. By contrast, goats browsed for more than 60% of their feeding time during the rainy season, and as the season progressed and the herbaceous component declined, the time spent browsing rose to more than 90% of the feeding time. The marked increase in browsing time by sheep in the dry season was not due to a reduction in their time spent feeding but was a real increase in the actual time spent browsing.

Although goats often consume most of their diet from the browse component, during some seasons or circumstances the grass/herbaceous component can be a major contributor to the diet. Published data indicate that when this occurs, herbaceous species can comprise more than half of the diet of goats. For example, Papachristou (1994) found that the herbaceous component could make up >50% of the diet of goats in a Mediterranean shrubland when herbage availability was high. This serves as a reminder that although goats have a much stronger preference for browse than sheep or cattle, goats are intermediate feeders, and the herbaceous component of the plant biomass can still contribute an important fraction of their diet.

Figure 9.3 Browsing goat showing typical bipedal stance (photo courtesy Dr. S.G. Solaiman).

Foraging Height—Bipedal Versus Quadripedal Foraging

It is frequently suggested that a major contributor to goats' achieving their higher intake of browse is their adoption of a bipedal stance, as shown in Figure 9.3. Indeed, some reports almost suggest that the adoption of a bipedal stance is what confers on goats their browsing success. Given the assumed importance of this, it is remarkable that there is so little quantitative evidence to support the notion. One must also remember that in a ruminant, the adoption of a bipedal stance comes at an energy cost, which might be expected to influence the time spent in bipedal browsing. How do goats browse, relative to other ruminants?

Sanon et al. (2007) recently reported foraging heights for co-grazing goats, sheep, and cattle in the Sahel. The mean and the maximum foraging heights recorded for the species follow:

- goats—1.65 m and 2.10 m
- cattle—1.47 m and 1.90 m
- sheep—0.87 m and 1.17 m

However, these heights are obviously influenced by the size of the species themselves. Differences in foraging heights become even more marked if they are recalculated in terms of the shoulder heights of the three animal species. In these terms, sheep and cattle foraged to similar mean heights (sheep 1.18, and cattle 1.21 times their respective shoulder heights) and maximum heights (sheep 1.58 and cattle 1.57 times shoulder height). By contrast, goats foraged to a mean of 2.42 times their shoulder height and a maximum of 3.08 times their shoulder height. Clearly, this could not have been attained without the goats adopting a bipedal stance for some of their foraging.

There are few estimates of the proportion of their feeding time that goats actually do spend in bipedal foraging. Pfister et al. (1988) measured the percentage of their foraging time that sheep and goats spent foraging within a series of strata defined as "ground level" (0–5 cm), "animal height" (6–75 cm), "overhead quadripedal foraging" (76–115 cm), or bipedal foraging (116–160 cm) in the wet, dry, and late-dry seasons in the Brazilian caatinga. Their recalculated data (Figure 9.4) confirm that goats spent much more time than sheep browsing above animal height, though it should be noted that in all seasons, both animal species spent a large proportion of their grazing time foraging at animal height or at ground level. This study also showed that most of the browsing above animal height occurred using quadripedal browsing; goats spent much longer than sheep browsing in this stratum. Bipedal browsing essentially only occurred with the goats, but even in this species, it accounted for only

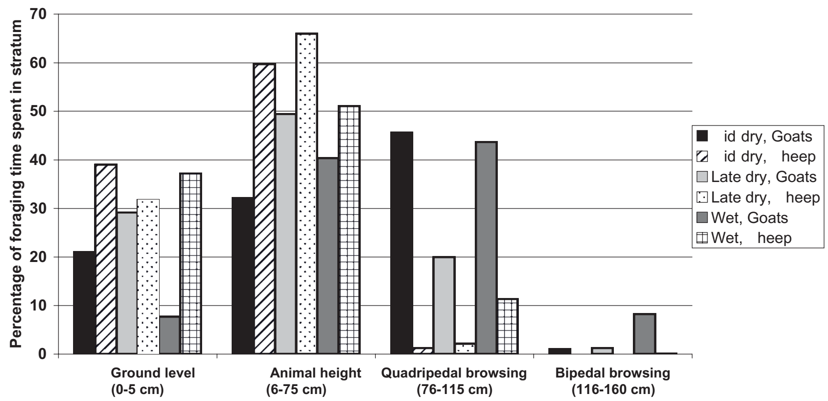

Figure 9.4 Comparison of the proportion of their foraging time spent by goats and sheep in four defined strata, during three seasons of the year (mid-dry season, late-dry season, wet season) in the Brazilian caatinga (recalculated from the data of Pfister et al., 1988).

about 8% of foraging time in the wet season. In the other two seasons, it accounted for much less.

In the data reported to date, goats have spent 10% or less of their foraging time in bipedal mode. Depending on the relative availabilities of forage in the different strata, goats may on occasions be forced to spend more of their foraging time in the bipedal stance. They are also known to climb into trees to obtain forage. To confirm the quantitative importance of these behaviors, we need more measurements of ingestive behavior under field conditions.

Breed, Gender, Age, and Physiological State of Goats

All of these factors can influence ingestive behavior and diet selection. There is evidence that Saanen goats browse for more of their total foraging time than Angoras, which graze for a much greater proportion of their foraging time. A practical consequence of this difference in feeding behavior is that helminth burdens may be more of a problem in Angoras, presumably because they forage in the layer occupied by nematode larvae. The interaction between feeding behavior, nutritional status, and helminth infestation is an area that would be worthy of detailed study in goats.

In general, juvenile goats spend 20–90% more of their day foraging than do adult goats. Differences in diet composition have also been reported for bucks versus nonpregnant, nonlactating does. Bucks consume a higher proportion of browse and tend to avoid grasses more than does. It has been suggested that sex dimorphism in buccal architecture may have contributed to differences in diet composition. Superimposed on the above effects can be an effect of physiological state. Depending on availability, forbs and grasses tend to make up a larger proportion of the diet of pregnant or lactating goats, compared with nonpregnant, nonlactating goats, which consumed more browse in their diet. Hence, there are effects of breed, gender, age, and physiological state on ingestive behavior and diet composition. Given the magnitude of the effects, future studies need to pay much more attention to controlling or at least reporting these factors.

Buccal Architecture, Dentition

The oral and dental features of goats are often mentioned when discussing their ingestive behavior, but the actual quantitative contribution of these mouth features has not been well defined. Mellado et al. (2007) recently used multivariate statistical procedures to relate diet choice by crossbred goats in Mexico to a range of oral measurements. Overall, there was a good relationship between the measured oral characteristics and the main plant species ingested (canonical correlation = 0.81). Muzzle width, incisor breadth, and jaw length were the main oral measurements associated with the extent of ingestion of spiny shrubs. Incisor length and the distance between the first molars had the dominant effect on the ingestion of grasses and coarse shrubs. The importance of incisor length is consistent with the known importance of incisors in the prehension and ingestion of grass.

A related effect is the state of the incisor teeth themselves (for example, missing, loose, or broken incisors), as influenced by such things as age. In ewe/lamb systems, it has been amply demonstrated that, independently of the effect of age, bad incisor dentition can reduce feed intake and animal performance. This is especially important in lactating ewes. In goats, Mellado et al. (2005)

estimated diet composition of dairy × criollo bucks and does and also recorded the integrity of their incisors. In general, goats with worn teeth avoided grasses and also had a higher preference for saltbush and for succulents. It is worth noting in passing that despite the marked effect of worn teeth on diet selection, gender differences in diet composition were greater than the effects of worn teeth.

The state of incisor dentition can be scored in a manner similar to the well-accepted body condition scoring systems. Given the magnitude of the effect of dentition on diet composition, more effort should be made in future studies to obtain dentition scores and to use these as explanatory variables when assessing differences in diet composition.

Clover Content and Clover Position Within the Sward

One of the most common assertions in popular writings about goat husbandry is that goats have a strong preference against clover and would rather not eat it. To take an extreme example, Hetherington (1977) suggested that "… (goats) will only eat ryegrass under sufferance and entirely ignore white clover." The evidence does not support either of these assertions.

In addition, one should also bear in mind that in such discussions, what is actually meant by "clover" is "white clover" (*Trifolium repens*). The preference of goats for other *Trifolium* species has not been reported, though goats are known to eat other legumes (e.g., Papachristou, 1994).

In a study with esophageal-fistulated Cashmere × feral goats grazing a perennial ryegrass/white clover pasture, Fraser and Gordon (1997) found that perennial ryegrass leaf laminae made up 66% of the diet of goats. Their diet also contained 9–18% white clover. The goats appeared to select positively for green clover leaf, relative to its availability in the total sward, but the clover proportion in the diet was similar to that at the sward surface, where the goats appeared to concentrate their grazing.

Penning et al. (1997) also examined the dietary preferences for perennial ryegrass and white clover in sheep or goats. Sheep grazed for longer than goats, and their extra grazing time was spent grazing clover. Dietary preference for clover, defined as the percentage of the total grazing time spent grazing clover, was 70% for sheep. The equivalent preference for goats was 52%, which certainly does *not* imply rejection of clover, but merely that goats have a lower preference for white clover than do sheep.

As a result of the somewhat lower preference for white clover demonstrated by goats, it has often been observed that whereas sward clover content falls under grazing by sheep, is relatively constant or rises when goats are grazing a ryegrass/white clover sward. This has practical consequences within mixed farming systems, because it raises the possibility of using a leader-follower grazing system in which goats are used to increase the clover content of a sward, which is then grazed by sheep.

In an attempt to understand the mechanisms underpinning such effects, De Rosa et al. (2002) extracted the "odor principles" from perennial ryegrass and white clover. They then sprayed distilled water or aqueous solutions of the odor extracts onto straw pellets. Goats had an almost two-fold preference for straw pellets sprayed with perennial ryegrass odor over those sprayed with distilled water. Pellets sprayed with white clover odor were less preferred than those sprayed with ryegrass extract, but were still preferred to those sprayed with distilled water. Once again, these data provide no support for the idea that goats have a low preference for perennial ryegrass or will "not eat" white clover.

Hence, taken together, these data provide little support for the notion that goats will reject or select strongly against white clover. Rather, they support the suggestion that goats will eat white clover but prefer it less than sheep, or that no selection against clover exists when it is part of the grazing horizon of the goat. Goats can and do consume perennial ryegrass as a major portion of their diet, when grazing sown swards of ryegrass/clover.

Presentation of the Biomass: Sward Height, Biomass, and Stocking Rate

In studies of ingestive behavior and diet selection, goats have been presented with different plant species in many ways: as individual plant species indoors; as mixtures of plants outdoors; or as the same material both indoors and outdoors. The method of presentation can itself alter the observed diet composition, because compared with housed goats, grazing goats are better able to select as they forage in a sward.

The published data for white clover selection by goats indicate that they are "top-down" grazers with a shallow biting depth, whereas sheep are more inclined to graze deep into the sward. In turn, this should render goats more susceptible to the effects of sward height, which does seem to be the case. Merchant and Riach (1994), for example, reported that goats found it more difficult to maintain intake and live weight gain as sward height decreased.

Based on this and on studies with sheep, a reduction in the amount of biomass on offer, or of sward height, due to increased stocking rate will influence both diet selection and intake. In general, stocking rate effects in goats have been similar to those seen in sheep. In co-grazing sheep and goats, the time spent eating and the grazing time as a proportion of total time both usually increase as stocking rate increases, while ruminating time and idle time tend to decrease.

Separate Versus Co-grazing: Previous Experience

The results of a number of studies indicate that the species of animal that previously grazed an area can potentially influence the diet choice of later animals by, for example, altering the legume content of the biomass as described above. Similarly, previous experience, preconditioning, or adaptation of animals to particular plant species can alter their future diet choice (e.g., Distel and Provenza, 1991). This should be taken into account when designing or interpreting studies of ingestive behavior and diet selection.

Ingestive behavior and diet selection can differ depending on whether the animal species involved are co-grazing or grazing as separate species. A detailed discussion of the merits or otherwise of co-grazing is outside the scope of this chapter. For a recent discussion of the major issues as they relate to goat production, the reader is referred to the excellent review by Animut and Goetsch (2008). One major advantage of co-grazing in relation to investigations of ingestive behavior is that it removes the confounding, which can occur between grazing site and animal species, when separate grazing occurs. For example, the use of co-grazing of the same area by ewes, does, and cows (Celaya et al., 2007) allowed a direct assessment of the degree to which their respective diet compositions overlapped.

Forage Odor/Flavor and Dry Matter Content

The diet choice of goats can certainly be influenced by flavor and by odor, as demonstrated by De Rosa et al. (2002). The DM content of forage can also influence ingestive behavior, though the response is not always clear-cut. Bateman et al. (2004) offered goat kids fresh forage from cereals and brassica crops and found that there was a 3-fold range in intake, which was strongly correlated with forage DM content ($r = 0.958$; $P < 0.01$). Their results also provided some evidence that goats prefer those feeds that allow a higher short-term intake rate.

Condensed Tannin Content of the Forage

Condensed tannins are a major class of plant secondary compounds that are often found in the browse species consumed by goats. It is beyond the scope of this chapter to present a detailed treatment of the effects of condensed tannins or other secondary compounds on animal nutrition and health. For a detailed discussion of these aspects, the reader is referred to excellent reviews by Foley et al. (1999), Mueller-Harvey (2006), and Shimada (2006).

Reference is often made to goats being able to consume more tannin-rich browse than sheep under similar conditions. Similarly, goats are said to somehow exhibit resistance to tannins or at least are less affected by plant secondary compounds than other animals. At times, this ability to cope with tannins has been linked to goats having proteins in their saliva that can bind to the tannins, though this remains a controversial area. For example, Snyder et al. (2007) asserted that goats are more tolerant of tannins "… because they have been reported to have proline-rich proteins … in their parotid salivary glands. …" They cited Mehansho et al. (1987) in support of this assertion, though there is no mention of goats in the latter paper.

There are actually two components embedded within comments like that made by Snyder et al. (2007). The first is that goats do have tannin-binding salivary proteins (TBSPs) and the second is that these TBSPs are in fact the proline-rich salivary proteins (PRP) that function as specialist tannin-binding proteins in some animals. It is true that TBSPs occur in the saliva of true browsers like deer and moose. It is perhaps because of this fact and the fact that goats often browse, that the idea has arisen that goats also cope with dietary condensed tannins through tannin-binding proteins in saliva. This idea merits closer examination.

There is no doubt that, through their greater intake of browse that may contain condensed tannins, goats may encounter a greater dietary intake of plant secondary compounds than sheep or especially cattle. Moreover, goats have a higher tolerance of bitter flavor than did sheep or cattle.

What is not clear from the research to date is whether TBSPs are present in goats, whether they are proline-rich proteins (PRPs), and whether they are functionally significant. As Foley et al. (1999) emphasized, the word "functionally" is most important. Even if TBSPs are detected, if they are present in very small amounts or have very low affinities for condensed tannins, then their functional significance is questionable.

Austin et al. (1989) found that there were TBSPs in the saliva of deer but not in the saliva of sheep and cattle (goats were not tested). Mole et al. (1990) subsequently tested for the presence of PRP in the saliva of lagomorphs, rodents, marsupials, and sheep and cattle. While salivary PRPs were regarded as "detectable" in the saliva of sheep and cattle, when scaled to body weight, these species had only 0.01–0.02% of the amount in the saliva of rodents, marsupials, or hares and rabbits. The PRP detected in sheep and cattle saliva also had a much lower affinity for tannins. These studies thus provide no evidence of there being functional PRP in the saliva of sheep and cattle.

More recent studies reviewed by Mueller-Harvey (2006) and by Shimada (2006) indicate that sheep and goat saliva contained (unidentified) TBSP with a reasonable affinity for condensed tannin. However, these TBSPs do not appear to be the PRPs usually associated with tannin-binding ability. Lamy et al. (2008) recently reported a comprehensive electrophoretic comparison and characterization of the salivary protein profiles of both sheep and goats eating a low-tannin diet. They also specifically tested for the presence of salivary PRP in both animal species and could *not* detect them. They suggested there was a need to repeat such measurements in animals fed high levels of tannin, but other evidence indicates that TBSP cannot be induced in the saliva of ruminant livestock by feeding high-tannin diets.

In summary, the search for TBSP in the saliva of ruminant livestock in general and goats in particular suggests that some TBSP may be present in saliva. Equally, it indicates that they are not the PRPs associated with tannin binding in true browsers. Whether the unidentified TBSP would be of physiological importance as a defense against high-tannin diets in goats is not yet established (Shimada, 2006).

Goats can nevertheless consume high-tannin diets without ill effect and because they excrete only a small proportion of dietary condensed tannin in feces, some other defense mechanism against condensed tannins must be operating. Two other possible mechanisms could allow the goat to tolerate high-tannin diets:

1. Quantitative studies of the fate of condensed tannins during gut transit have shown substantial losses between intake and feces (e.g., Perez-Maldonado and Norton, 1996), suggesting the possibility of microbial metabolism of tannins in the gut.
2. One might expect that a herbivore's intake of a feedstuff containing a secondary compound would be limited by its ability to detoxify the compound. The predicted consequence of this is that herbivores would choose a mixed diet to minimize the effects of the consumption of any particular secondary compound (see Foley et al., 1999). According to this hypothesis, the goat would consume its typically mixed diet not *because* of its overall capacity to detoxify secondary compounds, but in order to *avoid* a high intake of any one such compound. It should also follow that provision of a mixed diet of tannin-containing feeds would allow a greater total intake than could be achieved by eating any one feed. There is evidence to support this suggestion in goats. Rogosic et al. (2006b) found that feeding a mixture of three tannin-rich shrubs (*Quercus ilex, Arbutus unedo* and *Pistacia lentiscus*) to goats resulted in more than twice the intake achieved when the shrubs were fed separately.

The quantitative significance of these two mechanisms and the interactions between them have yet to be determined. This would be a fruitful area for future research.

Although goats can clearly tolerate high dietary intakes of condensed tannins, diet selection and intake can nonetheless be altered by supplementing foraging goats with polyethylene glycol (PEG), a polymer that binds to dietary condensed tannins. For example, Landau et al. (2002) supplemented Damascus goats with PEG (MW 4,000) in a rangeland dominated by lentisk (*Pistacia lentiscus*). Supplementation had no effect on the time spent foraging (Table 9.2) and in goats, which were not also offered alfalfa hay, resulted in a large increase in the proportion of their foraging time spent eating the tannin-rich lentisk. The time spent eating dry grasses decreased. When the goats were also offered alfalfa hay while on the range, the PEG supplement had no effect on the amount of time spent

Table 9.2 Effect of polyethylene glycol (PEG, MW 4000) on the feeding behavior of Damascus goats in a rangeland dominated by tannin-rich lentisk (*Pistacia lentiscus*).

Behavior	Control (–PEG)	+PEG
% of time spent foraging	44	39
Without hay supplement		
% of foraging time eating:		
Lentisk	41	73*
Dry grasses	28	12*
With hay supplement		
% of foraging time eating:		
Hay	30	26
Lentisk	46	62*
Dry grasses	13	10

Source: Adapted from Table 2 of Landau et al., 2002. Lentisk condensed tannin content = 22% DM.

*Control and +PEG values differ significantly ($P < 0.05$).

eating hay but still significantly increased the time spent browsing lentisk (Table 9.2). Goats offered PEG thus changed their patterns of diet selection. They also had a higher intake and maintained weight, whereas those not given PEG lost weight.

DIGESTIBILITY AND FEED INTAKE

There are many factors that influence the voluntary feed intake of grazing or browsing ruminants, including many of the factors that influence diet selection. These factors have been reviewed extensively recently (see for example, Dove and Mayes, 2005; NRC, 2007). The AFRC (1998) presents equations for the prediction of intake in housed goats. More recently, Luo et al. (2004) conducted an extensive review of the feed intake literature for "… lactating, Angora, growing and mature goats …," but once again, the emphasis was on the development of equations for predicting intake in housed animals. There is much less reviewed information on intake in the free-ranging goat, in part because of the difficulty in estimating digestibility and intake in free-ranging animals (Dove and Mayes, 2005). Of necessity, much of the information discussed below has thus been derived from housed goats. A degree of caution is required in extending this to the pasture or range situation.

An indicative, but by no means complete, summary of the factors influencing diet digestion and voluntary intake is given in Table 9.3. Clearly, the amount of plant material available, its spatial distribution, and its content of nutrients and plant secondary metabolites are major factors influencing intake. However, it is the animal itself that can be regarded as setting the upper limit to intake, through its need for and capacity to use nutrients at a particular age, body condition, and physiological state. This "potential intake" (CSIRO, 2007; NRC, 2007) is then constrained by features of the plant biomass on offer, by the animal's previous experience, by transactions within the gut, and by the intake of milk or supplement. A cornerstone of the approach is the notion of a "standard reference weight" (SRW) for a given breed, that is, the weight of the mature female with a condition score in the middle of the range used. Potential intake is scaled to this weight (see CSIRO, 2007; NRC, 2007) but will be different if the animal's current weight is below the SRW either because it is younger or if its condition differs, or both.

Both CSIRO (2007) and NRC (2007) took the view that intake equations derived for sheep could be applied equally to goats, arguing that published data did not warrant a separate treatment for goats. This assumption is examined further later in this chapter.

Table 9.3 Indicative summary of some of the factors shown to influence herbage intake in the free-ranging ruminant.

Plant factors	Animal factors
Species composition of plant biomass	Capacity to use energy/ physiological state
Mass, height, proportions of leaf, stem, or thorns in the plant biomass	Standard reference weight ("mature live weight")
Spatial heterogeneity—patchiness, height distribution	Current age, weight and body condition
Stage of plant development—vegetative versus reproductive	Previous experience with plant species on offer
Digestibility of the species on offer	Social interactions with other animals
Concentrations of plant secondary compounds in the plant species	Digesta load
Protein content of the species on offer	Intake of milk or of supplementary feed

Forage Digestion and Intake in Goats

A selection of the published comparisons of forage digestion and of intake by goats and sheep is given in Table 9.4. Almost all of the data are derived from studies with housed animals. Although details of the breeds and live weights of the animals are often provided, it is usually very difficult to assess age, body weight, and body condition in terms that would allow the use of the prediction equations in the published nutrient requirements. Moreover, the diets consumed by the two species are not always identical so that diet and animal species are confounded. These points should be kept in mind when assessing whether goats and sheep really differ in their digestion and intake of forage.

Forage Digestibility

Diets consumed in the reports summarized in Table 9.4 have ranged from high-quality (e.g., Doyle et al., 1984, diet A) to high-fiber, low-quality materials such as wheat straw (Reid et al., 1990). In general, published results do suggest that higher-fiber diets are digested better by goats than sheep, but overall, the data in Table 9.4 do not provide convincing evidence that diet digestibility is predictably and substantially higher in goats than in sheep. Tolkamp and Brouwer (1993), for example, surveyed published data

Table 9.4 Indicative summary of comparisons of digestibility and intake in goats and sheep.

Reference	Animals	Animal species with higher digestibility	Animal species with higher intake
Doyle et al., 1984	Angora goats; Merino sheep	Diet A,C—Neither Diet B—Goats	Diet A; Goats (g/d, not g/kg $W^{0.75}$)
Brown and Johnson, 1985	Toggenburg × Saanen castrated kids; Suffolk cross wether lambs	Overall, neither; sheep digested 65% wheat straw diet better	Goats (g/d); Neither (g/kg $W^{0.75}$)
Pfister and Malechek, 1986	Free-ranging castrated “hair sheep”; undefined goats	Overall, neither; sheep ate higher digestibility diet, wet season	Neither
Domingue et al., 1990	Angora × feral castrated goats; Border Leicester × Romney castrated sheep	Goats (winter only)	Summer—Goats Winter—Neither
Reid et al., 1990	Toggenburg × Alpine goats; Suffolk sheep	Neither	Neither
Tolkamp and Brouwer, 1993	Literature survey	Goats, but by mean of only 0.8 percentage units	ND
Papachristou, 1994	Free-ranging—breeds not defined	Cleared pasture—neither overall, sheep October only slashed/ native pastures—goats	ND
Perez-Maldonado and Norton, 1996	Castrated Cashmere goats; castrated Border Leicester × Merino sheep	Neither (OM, NDF, ADF, N)	Sheep (g/d) Neither (g/kg $W^{0.9}$)
Hadjigeorgiou et al., 2001	Castrated Blackface sheep; castrated Cashmere goats	Sheep (for DM, OM, NDF, ADF and N)	Goats (g/kg $W^{0.75}$)

ND = not determined.

on digestibility and concluded that while goats did tend to show higher digestibility capability than sheep, the mean difference between species was only 0.8 percentage units of digestibility, an amount which can be regarded as too small to be of any practical significance.

Forage Intake

On sown pastures dominated by perennial ryegrass, Merchant and Riach (1994) reported daily DM intakes of 26–88 g/kg$^{0.75}$ (1.1–3.7% of live weight) for castrated Cashmere goats. Intakes in lactating mixed-genotype goats were 57–140 g/kg$^{0.75}$, similar to ranges reported elsewhere for lactating sheep. Intakes by unweaned kids of 25–30 g/kg$^{0.75}$ are lower than published values for lambs and were also markedly lower than daily DM intakes in weaned kids, as might be expected. In general, all the above values are similar to those cited in the extensive review by Luo et al. (2004), which were as follows (minimum–maximum): growing goats 42.6–97.2 g/kg$^{0.75}$ (1.8–4.5% of live weight); mature, nonlactating goats 27.6–92.0 g/kg$^{0.75}$ (1.6–3.2% live weight); and lactating goats 31.7–151.3 g/kg$^{0.75}$ (1.0–6.3% of live weight).

In comparisons of feed intake by goats and sheep, it has sometimes been asserted that goats have the higher intake and that this is because of their higher ME requirement for maintenance, compared with sheep. There is strong evidence that goats do have a higher ME requirement for maintenance (AFRC, 1998; Sahlu et al., 2004) and that their requirement/kg$^{0.75}$ is more like that of cattle than of sheep. From this, it would follow logically that to maintain weight, goats would have to eat more of a given diet than sheep. However, this does not necessarily mean that *voluntary* feed intakes will be higher in the goat. This distinction between “the intake required to maintain weight” and “voluntary feed intake” needs to be more clearly acknowledged in future comparisons of the voluntary feed intake of goats with other species.

A selection of direct comparisons of voluntary intakes by goats and sheep is given in Table 9.4 (column 4). There are more instances where the intake by goats is higher, but given the number of instances where there is no difference, taken at face value, these empirical comparisons do not provide a convincing case for regarding daily intakes by goats as being higher than those of sheep. However, these data should be treated with some caution, for a number of reasons. First, there is a wide range of goat and sheep genotypes involved in the comparisons, and even when live weights are reported, it is very difficult to assess the extent to which the animals have reached mature weight, or whether there are differences in body condition between the goats and sheep involved in the comparison. Both relative size (current weight as a proportion of SRW) and body condition will affect intake (NRC, 2007; CSIRO, 2007). Moreover, for the field studies (Pfister and Malechek, 1986; Papachristou, 1994), the diet composition differed between goats and sheep and was thus confounded with animal species.

Hence without further corroborating evidence, one cannot yet conclude that goats and sheep differ in voluntary feed intake. Although there seems little doubt that the feed intakes required to maintain live weight are higher in goats than sheep, the issue of whether goats have higher voluntary feed intakes is still unresolved.

FEEDING HOUSED GOATS, SUPPLEMENTARY FEEDING, DROUGHT FEEDING

Goat production systems can often rely on the natural supply of pasture and/or browse, but there will be seasons, years, or periods of high production when extra feed has to be supplied by the manager (supplementary feeding) or when animals have to be fed during drought. Under these circumstances, questions of preference and feeding behavior become even more important. In addition, dominance hierarchies within the goat herd, which may not usually influence daily management, become a major consideration. The management of feeding under all of these circumstances has a strong economic dimension, for as Solaiman (2006) points out, from one-half to two-thirds of the variable costs of production are those related to feeding. Unless supplementary or drought feeding is managed well, enterprise profit will rapidly be eroded by the costs of feeding. For useful and detailed discussions of feeding management issues, the reader is referred to Bateman et al. (2004), McGregor (2005), and Solaiman (2006).

Feeding of Housed Goats

The highly selective feeding of goats applies equally indoors, though goats that are too hungry or too full will discriminate less between feeds (Morand-Fehr, 2003). Goats in general have a strong preference for dry feed to be in the pelleted form rather than flour or meal form (Morand-Fehr, 2003; Bateman et al., 2004). The main reason for this seems to be the irritation caused to the upper respiratory tract by the consumption and inadvertent inhalation of fine, dry feeds. This preference appears to apply equally to young goats (Bateman et al., 2004) as well as to adults (Morand-Fehr, 2003) and in part also relates to the fact that pelleted diets allow a more rapid eating rate. As might be expected, pelleted rations that consist of 5- to 10-mm pellets, as might be fed to sheep, are preferred by goats to larger pellets (15–20-mm) typical of the kind fed to cattle (Pinkerton and Pinkerton, 2008). Goats prefer dry diets fed in meal/flour form to have slightly higher moisture content because this allows a degree of agglomeration and, again, a faster intake rate with less irritation (Morand-Fehr, 2003). However, liquid diets such as those based on molasses do not appear to be preferred by young goats (Bateman et al., 2004).

When trough-fed, housed goats consume both "main meals," which account for the bulk of their intake, and smaller "secondary meals." Main meals usually occur immediately after feeding, and the amount consumed will be a function of the rate of intake which the ration permits. The manager must therefore ensure that the physical form of the diet allows the animals to consume the desired quantities. Housed goats will also consume a feed more readily if they have had some previous experience of it (Distel and Provenza, 1991).

An aspect that assumes much more importance in housed animals than in free-ranging goats is the effect of dominance hierarchies on eating behavior. When it comes to consumption of feed from a trough with limited available space, the comment by Pinkerton and Pinkerton (2008) is relevant:

> Gracious, equitable sharing is simply not a caprine characteristic; greed, aggression and sheer size conspire to "cheat" the more civil and/or smaller goats.

The manager must therefore ensure that this "greed and aggression" is minimized, mainly by ensuring that trough space is adequate for all goats to be able to feed. As a generalization, 25–30 cm of trough space/kid should be allowed, or 45–50 cm/adult. A smaller allowance of trough space will almost certainly result in aggressive behavior and in the more submissive goats consuming less.

Supplementary Feeding under Field Conditions

A number of the above comments about the feeding of housed goats apply equally well under field conditions, especially if goats are grazing sown pasture. When supplements are offered to animals in the field, true supplementation (i.e., the supplement is offered and there is no reduction in forage intake) is actually a rare event. The most common outcome is for the consumption of the supplement to result in a reduction of the forage intake. The extent of the reduction, per kg supplement fed, is referred to as the "substitution rate." If supplementary feeding is managed properly, substitution rate will usually be <1 so that total intake will in fact be increased, as intended. Moreover, since the quality of the supplement (for example, digestibility) is often better than the average of the forage on offer, the digestible DM intake may be increased by an even greater proportion.

A range of factors influences the degree of substitution between supplement and forage. Generally speaking, substitution will be higher under the following circumstances:

1. Substitution rate increases when more forage is available or when forage is of higher quality, or if higher quality supplements are fed, because of associative effects between the digestion of supplement and the digestion of the fiber of the forage.
2. It is usually greater (though not always) if more supplement is fed or if the supplement is fed infrequently.
3. For a given quantity and quality of forage on offer, the degree of substitution can be altered by the animals' physiological state. For a given forage base and supplement, animals with a higher nutrient demand (such as lactation) will usually exhibit a lower substitution rate.

Under field conditions, supplements may be offered by trailing them along the ground in a thin stream. This can ensure that all animals, including the so-called "shy feeders," will get a share, but there is also an interaction with feeding frequency. If supplements are trailed out infrequently, then dominant animals can overeat on the day of feeding, with resultant digestive disturbances if, for example, whole grain is being fed. If supplements are fed in troughs, then the above comments about allowing sufficient trough space apply equally in the field, if not more so. For example, allowing too much trough space can also result in aggressive behavior by dominant goats, by allowing them the space to claim and defend a "territory" (Solaiman, 2006).

The economics of supplementary feeding are much more favorable if animals take only a short period to begin eating the supplement. As discussed above, this is in part a function of their previous experience. Goats will more readily eat a supplement if they have experienced it before, even pre-weaning. For supplementary feeds that the herd has not previously experienced, a useful management tool is to include within the herd a few "experienced" (usually older) animals that have had some experience of the supplement. This has been shown to increase the supplement intake of the inexperienced animals.

In low-cost, more extensive production systems, often characterized by a generally lower-quality forage base, it may be appropriate to supplement animals using feed blocks, constituted to provide nutrients in poor supply in the diet (for example, minerals, rumen-degradable N). In general, the evidence that the provision of feed blocks results in an increase in forage intake by goats is inconclusive. However, where the forage contains plant species with condensed tannins, feed blocks may be a cost-effective way of supplementing with PEG, to overcome the negative effects of condensed tannins and to increase intake.

Drought Feeding of Goats

Drought feeding differs from other forms of supplementary feeding in that the emphasis is on survival of the herd and not on high levels of animal production. This alters what can and ought to be done. For a detailed and very practical treatment of the issues involved in drought feeding of the goat herd, the reader is referred to McGregor (2005). In drought feeding, the issues of prior experience of the feed, or of a training or introductory period for feeds such as whole grain, are equally relevant. Substitution may be less of an issue, because by definition, drought will involve a shortage of forage. However, for exactly the same reason, animals in drought will often be hungry, so careful management of feeding is very important to avoid the dominance effects described above. If the drought feed is offered as a feed trail, it may be necessary to offer a space of somewhat more than 0.5 m/animal.

Drought conditions may also imply hot conditions, and under these circumstances, dominant goats will not only fight for space at the feed trough, but also for access to water and shade (McGregor, 2005). They may even exclude submissive animals from these areas. This means that the location of drought feeding areas and the frequency of feeding must be very carefully considered in relation to the location and nature of shade areas and watering points.

SUMMARY

The capacity of the goat to select and consume substantial quantities of browse places it in a unique position, compared with other domesticated ruminants, to contribute to animal production and thus human well-being, especially in regions where sown pastures cannot be grown. It does this in part by being able to actively browse in both the quadripedal and the bipedal modes. Popular writings on goat feeding behavior claim that bipedal grazing is the key to browsing success, but when measurements have been made, a surprisingly small proportion of time is spent browsing in this mode. Nevertheless, goats undoubtedly browse much more than do sheep or cattle.

However, as this chapter has also demonstrated, the goat can also use sown pastures well and is thus a successful intermediate feeder. Claims that goats will reject legumes like white clover are not supported by experimental results, which show that goats can produce well on perennial ryegrass/white clover pastures.

Published evidence suggests that goats do tend to digest forage slightly better than do sheep, but by an amount which would be of little practical significance. Similarly, the evidence that goats eat more of a given diet than sheep is equivocal. Goats do appear to have a higher ME requirement for maintenance, so to maintain weight, they would need to eat more of a given diet than sheep. However, it does not necessarily follow that goats will have higher *voluntary* intakes than sheep.

A fruitful area for future work on ingestive behavior and intake by the goat would be to resolve the issue of how it deals with the high condensed tannin loads with which it is occasionally confronted. There is no doubt that it does cope, but the mechanisms remain unclear. Recent experimental results suggest that the role of tannin-binding proteins in saliva may have been overstated, but further work is required to clarify this.

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