BROWSE SHRUBS AND TREES AS FODDER FOR RUMINANTS: A REVIEW ON MANAGEMENT AND QUALITY

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ABSTRACT

This paper reviews the main determinants of productivity and quality of forage from browse species and highlights the usefulness of browse plants as fodder sources. The effect of secondary plant metabolites on forage quality and the consequential effects on browse acceptability and intake are presented. Condensed tannin (CT) is emphasised due to its nutritional advantage if it occurred at an acceptable level (< 50 gCT/ kg DM). The practical implication of this limit has been questioned and it is speculated that it may vary with plant species as the function of CT depends on its structure and level of polymerisation. Gaps in our knowledge of browse plants are identified and areas requiring further research are indicated.

Keywords: B*rowse yield, Cutting, Browsing, Condensed tannin, Ruminants*

INTRODUCTION

The leaves and soft stems of shrubs and trees (browse or topfeed) are important in ruminant nutrition (Gutteridge and Shelton, 1994). Browse may also include fruits and pods of shrubs and trees (Aganga and Tshwenyane, 2003). Browse use spans from the temperate to the tropical areas of the world, particularly in areas prone to drought (Lefroy *et al*., 1992), arid or semi-arid and montane zones of Africa (Otsyina and Mckell, 1985), Asian-Pacific regions (Brewbaker, 1986) and North America (McKell *et al*., 1972). Browse use has a long history (Robinson, 1985) but with the advent of cultivated pastures it has attracted less attention due to the advantages of cheaper establishment and easier management of herbaceous pastures.

The potential of browse species in ameliorating herbaceous feed shortages in livestock systems has been demonstrated empirically. However in practice, the provision of adequate and quality browse is beset with difficulties. Research results have been conflicting due to the diversity in experimental locations and sites, as well as the varied plant species used (Horne *et al*. 1986; Stur *et al*. 1994). It is the intent of this paper to recount the management and quality issues on browse species over the last four decades. The focus is on the main determinants of productivity and quality of forage from browse species and highlights the usefulness of browse species as fodder sources. Gaps in our knowledge of these useful plants are identified and areas requiring further research are indicated.

Browse shrubs and trees as source of fodder for ruminants

Woody plants, usually low growing trees and shrubs, are useful fodder for livestock and wildlife. They may be leguminous or non-leguminous, but leguminous plants are favoured because of their ability to fix nitrogen and their relatively high foliar nitrogen (protein) levels (Gutteridge and Shelton, 1994). Browse species provide flexibility in the timing of their use, and in particular provide green feed when grasses and other herbaceous materials are dry (Lefroy *et al*., 1992).

Compared to grasses, most leguminous fodder trees and shrubs have higher concentrations of crude protein, minerals and neutral detergent fiber (Dicko and Sikena, 1992), and generally a lower concentration of acid detergent fiber and dry matter digestibility (Le Houerou, 1980). Nutrient levels and digestibility of fodder trees and shrubs also decline slightly over the growing season and hence their potential value as drought fodder for livestock (Baumer, 1992). Furthermore, the early growing season of browse species occurs in the late dormant season of grasses (Bergstrom 1992) thus providing a potential early supplement to pasture. Recent work in Northern Australia showed that the addition of *Leucaena leucocephala* into pastures increased the quality and quantity of cattle diets resulting in increased animal production (McGowan and Matthews, 1992).

Many woody plants of the African savannas are browsed or topped for dry season feed for livestock such as sheep, goats and cattle (Le Houerou, 1980; Otsyina and McKell, 1985). Mabey and Rose Innes (1966) reported that cattle fed on *Antiaris africana* browse had weight gains of 82g/day. In Australia, trees and shrubs such as *Chamaecytisus palmensis* and *L. leucocephala*, *Acacia* spp., *Atriplex* spp., *Brachychiton populneum*, and *Salix* spp are cultivated as fodder (Lefroy *et al*., 1992). Oldham *et al*. (1991) found that young ewes that grazed *C. palmensis* grew significantly more wool than their flockmates on supplemented dry pasture (Table 1). In Bangladesh, Kibria *et al*. (1994) found that goats fed leaves of *Artocarpus* sp and *L. leucocephala* gained weight at a rate of 43.9 and 52.8g/day respectively. Further, in New Zealand browse species such as *Ulex europaeus*, *C. palmensis* and *Salix* species are used as supplementary fodder for sheep, goats and deer during summer drought (Borens and Poppi, 1990; Oppong *et al*., 2001).

Management and quality of browse species

The use of browse species involves defoliation either by cutting or by herbivory. The process has several implications for the productivity, quality of the forage and persistence of the species. The amount and type of tissue removed, and when the loss occurs in relation to plant development and the prevailing environment (Richards, 1993), are most important in determining the impact of defoliation on plants (Crawley, 1983). Loss of meristematic tissues usually has a much greater effect on regrowth than the proportional loss of biomass, leaf area or plant resource (Richards, 1993).

There is usually a decline in total non-structural carbohydrates of roots and remaining shoot parts after defoliation (George and Mckell, 1978). Donart and Cook (1970) found that the defoliation of herbaceous plants early in the growing season was more detrimental than late in the season while the reverse trend occurred in browse plants. The depletion of

Table 1: The mean (± sem) clean fleece weight (CFW) and mean (± sem) fibre diameter (FD) of young ewes grazed on *Chamaecytisus palmensis* or dry pasture over summer/autumn

Forage type	No. of Ewes	CFW (kg)	FD (mm)
Chamaecytisus palmensis (31 weeks)	27	3.0 (0.08)	21.3 (0.22)
Pasture	30	2.2 (0.05)	20.5 (0.21)

Adapted from Oldham *et al*. (1991)

stored reserves caused by excessive defoliation results in reduced vigour and plant growth and in extreme cases can result in death of plants.

Plants also react to herbivory by providing protection from grazing through the production of toxins or morphological features such as toughness or spines and by compensating for the biomass removed (Bergstrom and Danell, 1987). Thus compensatory growth in plants may alleviate the potential deleterious effects of tissue damage, whether to vegetative or reproductive organs (McNaughton, 1983). Danell *et al*. (1985) reported that browsed birches produced shoots with larger and more chlorophyll-rich leaves than did unbrowsed birches. Further, Du Toit *et al*. (1990) also noted that shoot regrowth in heavily browsed *Acacia nigrescens* more than compensated for herbivory, as net annual shoot extension was not significantly different from that in lightly browsed trees.

Browse productivity

Forage yield from browse species is affected by several interacting factors, some of which are too complex to manipulate. In general, browse yield is affected by climate, soil, plant spacing, plant stock used, management history, age of plant at harvest and herbivory. Climate is difficult to manipulate except for the use of irrigation to overcome soil moisture deficits due to inadequate rainfall. The other factors can be altered relatively easily but the practical expediency of such intervention depends on critical factors such as the profitability and percent yield increment. Most browse yield data have not been reported with the associated ages of the plants at the time of harvest, which reduces their value for proper utilisation assessment (Skerman *et al*., 1988) and also for comparing yields among species and even within species. Tree age influences yield by its effect on root development and distribution (Adejumo, 1992) and stump diameter (Blake, 1983). Increased stump diameter may result in increased potential growing buds, which affects coppicability and yield from cut plants. Browse yield data for some browse species in tropical, subtropical and temperate regions of the world are presented in Table 2.

Table 2: Browse yield from legume and non-legume species

Legume species	Plant part	Age at harvest	Yield tDM/ ha/yr	Source
Gliricidia sepium	leaf		2 - 20	Simons and Stewarts, 1994
Luecaena leucocephala	leaf+soft stem		3 - 30	Shelton and Brewbaker, 1994
Sesbania spp	leaf+soft stem		4 - 12	Gutteridge, 1994
Calliandra calothyrus	leaf+soft stem		7 - 10	Palmer *et al*. 1994
Albizia lebbeck	leaf+soft stem		1.7 - 2.5	Lowry *et al*. 1994
Chamaecytisus palmensis	leaf+soft stem	1 year	3 - 9	Lefroy *et al*. 1994
		4 years	2.9	Douglas *et al*. 1996
			14	Snook, 1994
Non-legumes species				
Salix matsudana x *alba*	leaf+soft stem	1 year	1.1	Douglas *et al*. 1996
		3 years	3.0	Oppong *et al*. 1996
		4 years	4.7	Oppong *et al*. 2001
		5 years	2.7 - 7.1	Hathawy, 1986
Salix kinuyanagi	leaf+soft stem	1 year	1.7	Douglas *et al*. 1996
		3 years	2.3	Oppong *et al*. 1996
		4 years	2.9	Oppong *et al*. 2001
Populus spp	leaf+soft stem		0.2 - 1.0	Anon, 1995

Effects of cutting on browse yield and quality

The effects of cutting height and frequency on yield and nutritional quality of forage from many browse plants have not exhibited a consistent pattern. Cutting height usually did not influence forage yield, but cutting frequency exerted greater effect on yield (Stur *et al*., 1994).

However, Tarawali *et al*. (1996) observed that in *Gliricidia sepium* lower cutting heights (30 cm) yielded more dry matter than those cut at 50 cm and 70 cm during the first harvest. Defoliation responses usually occur within a limited range of stump height, below or above which cutting height has no influence on yield and quality of forage. For example, Catchpole and Blair (1990) reported that leaf yield of *Leucaena leucocephala* was unaffected by cutting heights of 1.5-2.5m above ground.

Guevaria *et al*. (1978) also found increased dry matter yield with less frequent cutting of *L. leucocephala*. Dry matter yield of *L. leucocephala* declined (Karim *et al*., 1991) with frequent cutting due to an increased number of recovery phases, which affected the recovery of carbohydrate reserves and lowered the rate of dry matter production (Erdmann *et al*., 1993). Erdmann *et al*. (1993) reported a significantly greater number of shoots on *Gliricidia sepium* cut at 25cm above ground compared to those cut at 100cm. They attributed the difference to the 100cm stools not having to grow the same quantity of leaves, as many of them were retained on the stumps, while the 25cm stools were devoid of leaves. In contrast, a similar study on *L. leucocephala* showed a greater number of shoots on stools cut at 90-cm (Jama and Nair, 1989) compared to 30cm cutting height.

Everitt (1983) noted that the crude protein (CP) and phosphorus (P) concentration in regrowth of *Celtis pallida*, *Zanthoxylum fagora*, and *Ziziphus obtusifolia* cut on various dates were higher than in current growth from uncut plants, at two months after cutting. Cutting created nutritious sprouts that were more palatable and readily available due to reduced plant height and restrictions to browsing such as sharp thorns, often prevalent on mature stems.

Effects of browsing on browse yield and quality

A plant's response to browsing depends on plant genetics, development stage, intensity and frequency of defoliation, plant parts affected, and modifying effects of environmental factors (Teague, 1985). The consequences of grazing intensity and frequency on individual plants and plant communities are well documented (Vallentine, 1990). For example, In South Africa, Du Toit *et al*. (1990) compared heavily and lightly browsed trees of *Acacia nigrescens* and found that the net shoot extension was not significantly different between heavy and light browsing by giraffe and impala. The heavily browsed trees grew rapidly to compensate for the frequent removal of browse and had reduced condensed tannin (CT) levels and higher N and P contents in leaves compared with the lightly browsed trees.

Heavy and less frequent browsing of *Coleogyne ramosissima* by goats (Provenza *et al*., 1983) and *Betula* species by moose (Danell *et al*., 1985) increased forage yield and quality compared to unbrowsed plants. Less frequently browsed plants outyielded those browsed frequently, and had forage which was lower in CT (Provenza *et al*., 1983; Danell *et al*., 1985).

Nutritive value of browse for ruminants

Nutritive value encompasses all nutritional attributes of forage in relation to its overall value to the consuming animal (Van Soest, 1994). This term is often used in a restrictive sense of forage quality (Mertens, 1994) or feeding value (Ulyatt, 1973), including protein content and digestibility. Digestibility is a major determinant of nutritive value (Ulyatt, 1973) and provides the best practical evaluation of the quality of the animal's diet (Holechek *et al*., 1982). The nutritive values of some browse species are shown in Table 3. These values are normally given without indicating the age of the material chemically analysed and which in no

Table 3: Nutritive value of legume and non-legume browse species

Legume species	Plant part	Crude protein (%DM)	Digestibility (%DM)	Source
Gliricidia sepium	leaf	20 - 30	60 - 65	Simons and Stewarts, 1994
Luecaena leucocephala	leaf+soft stem	26	50 - 70	Shelton and Brewbaker, 1994
Sesbania spp	leaf+soft stem	20 - 25	66 - 75	Gutteridge, 1994
Albizia lebbeck	leaf+soft stem	16 - 23	45 - 70	Lowry *et al*. 1994
Chamaecytisus palmensis	leaf+soft stem	15	70	Lefroy *et al*. 1992
Non-legumes species				
Salix matsudana x *alba*	leaf+soft stem	14	68	Oppong *et al*. 1996
Salix kinuyanagi	leaf+soft stem	12	61	Oppong *et al*. 1996
Populus spp	leaf+soft stem	13 - 15	66 - 70	Anon, 1995

doubt may influence these values especially that of nitrogen (protein). More active tissues usually have greater quality. For example, live leaf has higher quality than live stem (Oppong *et al*., 2001) because of the higher photosynthetic activity. Nutrient quality declines with decreasing rate of development and the outset of senescence.

Effect of secondary plant metabolites on ruminants

Most browse plants contain diverse secondary metabolites that can deter animals from feeding on the foliage. Secondary metabolites vary in their potency as anti-feedants (Bryant *et al*., 1992), primarily due to toxicity of the metabolites rather than digestion inhibition (Bryant *et al*., 1991). Common secondary plant metabolites are presented in Table 4 (Barry and Blaney, 1987). Secondary metabolites have evolved as a defence mechanism of woody plants against herbivory. This is an adaptive mechanism used by woody plants growing on low fertility soils (Jackson *et al*., 1996) to compensate for their inability to grow rapidly beyond the reach of most browsing animals. Of all the secondary plant metabolites that affect the quality of browse, soluble phenolics occur most widely in woody plants, with tannins receiving the most attention (Rittner and Reed, 1992). Tannins occur either as hydrolysable or condensed tannins, but the dominant forage tan-

Table 4: Common secondary compounds affecting the feed value of forages

Class	Examples
Alkaloids	Pyrrolidizine alkaloids, Fescue alkaloids
Glycosides	Cyanogenic glycosides, Coumarin, Isoflavones and coumestins
Mycotoxins	Zearalenone, Trichothecenes, Sporidesmin, Phomopsin, Lolitrems, Swainsonine, Slaframine, Ergot alkaloids.
Polyphenols	Tannins
Proteins and Amino acids	Bloat-producing protein, Mimosine, Indospicine
Simple acids and their salts	Oxalates, Nitrates, Fluoroacetate
Steroids and terpenes	Saponins

Adapted from Barry and Blaney (1987)

nins are usually of the condensed type (Kumar and Singh, 1984) in woody plants (Rittner and Reed, 1992). Examples of browse species with varying concentrations of condensed tannins (CT) are presented in Table 5. CT at low concentrations (20-40 g/kg DM) are nutritionally beneficial through decreased degradation of dietary protein in the rumen, and increased protein availability for digestion and absorption leading to good animal performance (Waghorn *et al*., 1990).

Many evergreen shrubs such as *Artemisia* spp. and *Quercus* spp. have high (> 76 gCT/kgDM) levels of CT and other anti-nutritional factors. In woody plants, results indicate a negative correlation between CT content and palatability. CT binds forage protein and reduce their availability and digestibility, and they also restrict microbial fermentation of structural carbohydrates (Van Soest, 1994).

Some studies have used polyethylene glycol (PEG) to bind with CT thereby enabling the effects of CT to be determined by comparing responses from CT (no PEG) and non-CT (+PEG) treatments (Barry and Blaney, 1987). This technique was used to determine that high concentrations of CT (60-90g/kg DM) in *Lotus pedunculatus* depressed cell wall digestion, voluntary intake and liveweight gain while low concentrations (20-40 gCT/kg DM) improved nutrient utilisation by ruminants. The latter occurred principally by reducing forage protein degradation in the rumen, thus simultaneously eliminating bloat and increasing amino acid supply to the animal (Barry and Blaney, 1987; Waghorn *et al*., 1990; Jackson *et al*., 1996).

Nastis and Malechek (1981) found reduced voluntary intake and digestibility of cell constituents in goats' fed *Quercus* browse with high CT concentration. Daily drenching of sheep fed leaves of *Acacia aneura* with PEG (Jones and Wilson, 1987), or brushtail possum (Cork, 1984) fed eucalyptus, resulted in increased food intake and cell wall digestion. Sheep and steers grazing *Sericea lespedeza* consumed more of the low CT containing plants than those with high CT concentrations (Kumar and Singh, 1984).

Our knowledge of the attributes of CT in woody species is limited making it difficult to extend the implications of CT values of herbaceous forages on ruminants to browse. Cautiously we are inclined to believe that the limit (< 50 gCT/kg DM) set as a rule of thumb for any nutritional benefit (Waghorn *et al*., 1990) may not be appropriate for all forages. We suggest that the nutritionally beneficial CT level should be set for different types of forages. Kumar and Singh (1984) reported anomalies in the digesti-

Table 5: Condensed tannin (CT) concentration (g/kg DM) in leaves harvested from browse species (estimates from butanol-HCl method; samples were prepared by freeze drying)

Species	**Total CT (g/kg DM)**
Acacia boliviana	17.5
Arachis pintoi	33.6
Calliandra calothyrus	57.8
Cassia sp.	93.2
Flemingia macrophylla (17405)*	240.1
Gliricidia sepium	40.7
Leucaena diversifolia	92.5
Leucaena leucocephala cv Cunningham	60.3
Leucaena pallida	67.2
Tadehagi triquetrum	145.6

***Accession number; Adapted from Jackson *et al*. 1996**

bility of proteins of various tree leaves and explained that these may be due to the type of tannin, protein precipitation capacity and degree of polymerization. Our contention is that the CT of woody plants may be functionally different to that of herbaceous plants since the structure and extent of polymerisation of CT determines its biological activity (Kumar and Singh, 1984; Clausen *et al*., 1990). Moreover, chemical defenses of woody plants vary by growth stage and by plant parts with growth stages. For example, the buds and internodes of young and adult stages of *Betula resinifera* differ in chemical defenses (Bryant *et al*., 1991).

Secondary metabolites and selective behaviour of ruminants

Ruminants select a diet from the plants available to them (Gordon and Lascano, 1993). The grazing process is a system of diet selection interacting with the animals' physiological needs. That is, animals seek the most energy-efficient sources of forage (Stuth, 1991). The discriminatory nature of herbivore in the choice of forage is mainly due to quality and chemical defence of the forage plants. Abundant evidence shows that food selection and ingestion is regulated by toxins rather than by inhibition of protein or carbohydrate digestion (Bryant *et al*., 1991).

Little information exists on diet selection by ruminants faced with conflicting constraints that may arise from the presence of secondary plant compounds. For example, plants with high levels of CT may contain high level of nutrients and energy, but the astringent sensation animals probably experience when consuming them may lead to their rejection, which could be a nutritional mistake (Provenza *et al*., 1991). The rejection of CT containing plants or plant parts is presumably an evolved response by animals to the negative effects tannins have on forage digestibility and therefore animal fitness (Rhoades, 1979). Studies of domestic and wild animals fed unpalatable browse normally available to them, or artificial diets treated with extracts from this browse, confirm the importance of toxicity (Bryant *et al*., 1991).

CONCLUSIONS AND RESEARCH NEEDS

Browse species are potentially indispensable and nutritionally beneficial components of the animal's environment and they must be given due research attention. Data on the management and use of browse species are conflicting, therefore, the feed advantage of browse compared to alternative feed sources is disputed (Oppong, 1998). Several trials have been conducted in semi-arid to arid areas of the tropics, with few in temperate regions. Numerous potential browse species are available in temperate areas, which should be thoroughly studied to generate data for the development of appropriate managements for these plants to provide good quality fodder for dry periods in these areas.

Browse species react differently to cutting and browsing and any species evaluation must be based on both management techniques. Preference studies on browse species will determine the most nutritionally beneficial species for ruminants and based on the preference rating species could be selected for cultivation.

Systematic effort should be made to evaluate in detail known browse species for their yield potential and fodder quality. Studies are required into improving browse yield through (a) breeding of browse species that are fast growing and high yielding, amenable to browsing through low canopy formation and improved morphology to enhance accessibility and persist under intense and frequent use, and (b) respond to soil amendments such as fertilisation. More animals' responses on browse should be determined. The effect of browse species on associated species, especially in a tree-pasture system also deserves systematic study. The importance of secondary plant metabolites especially condensed tannins should be studied, as woody plants tend to have high concentrations of CT and their nutritional role in ruminant production systems need more attention.

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