Conservation Science W. Aust. 4 (3) : 117–124 (2002)

Livestock potential of Australian species of *Acacia*

ROBYN A. DYNES[1] AND ANTHONY C. SCHLINK[1]
[1]CSIRO Livestock Industries, Private Mail Bag 5, Wembley, Western Australia 6913
Email: Robyn.Dynes@csiro.au

SUMMARY

Trees and shrubs have long been considered important for the nutrition of grazing and browsing animals in Australia, particularly where the quantity and quality of pastures is poor for long periods The economic or feeding value of *Acacia* species for animal production will depend on when the nutrients are available (i.e. does foliage/seed/pod production match feed gap or drought?) and the concentrations of essential nutrients and secondary compounds in foliage, seeds or pods.

The feeding value of any forage is a function of a number of characteristics of the species, including its availability, accessibility, nutrient availability, chemical composition and presence or absence of secondary compounds. The accessibility of foliage and/or seeds and pods on acacia trees and shrubs is likely to limit the performance of grazing ruminants, although the potential exists to select lines more suited to grazing species. Forage digestibility is an important component of nutritive value, but only limited data exist for Australian *Acacia* species. The digestibility of *Acacia anuera* is reported to be between 39% and 64%, suggesting that there are lines suitable for animal production. Mineral composition of Australian acacias varies considerably between species, ranging from toxic to inadequate for livestock production. Plants that grow in inhospitable environments commonly contain secondary compounds which play a role in plant survival. Acacias are reported to have a wide range of secondary compounds including tannins, oxalates, cyanides, saponin, amines, alkaloids, fluoroacetate and other unidentified toxins. The level and presence varies with both species and plant part. Options for reducing the impact of secondary compounds are discussed.

Utilisation of acacias in farming systems could be improved through selection of species to provide feed for livestock during feed gaps and droughts, as long as issues of fodder accessibility and secondary compounds are overcome. An effective selection process will require screening a very large number of samples to determine plant quality. Near-infrared reflectance spectroscopy (NIR) is a rapid, inexpensive and accurate method and requires only small samples of plant material.

INTRODUCTION

Trees and shrubs have long been considered important in the nutrition of grazing and browsing animals in Australia, particularly where the quantity and quality of pastures are poor for long periods (Lefroy *et al.* 1992). Foliage from trees and shrubs has the potential to provide both protein and energy supplements during the annual feed gap or during drought (McMeniman and Little 1974; Bhattachrya 1989; Reed *et al.* 1990). Several species of *Acacia* are recognised by graziers for their feeding value during drought (Chippendale and Jephcott 1963; Everist 1969). The economic value of these species to animal production will depend on when the nutrients are available (i.e. does foliage/seed/pod production match feed gap or drought?) and the concentrations of essential nutrients and secondary compounds.

Investigations of the potential of trees and shrubs (particularly acacias) as fodder sources for livestock in Australia has been limited to the more widespread, better-known fodder species such as Mulga (*Acacia aneura*). The accumulated data are now sufficient for *A. aneura* to become incorporated into pasture grazing systems models (Hall *et al.* 2000). For most acacia species there are limited or no data, making it impossible to select and exploit variation within and between species to maximise animal productivity.

This paper addresses the potential of Australian species of *Acacia* for selection for animal production, their nutritional value, and the opportunities for incorporating them into grazing systems. It also looks at intraspecific variation in feeding value, secondary compounds and how the secondary compound issues have been addressed for ruminant livestock.

FEEDING VALUE OF *ACACIA*

Feeding value of any forage is a combination of dry matter availability (and accessibility) and the value of the ingested dry matter for use by the grazing animal (nutritive value, NV). Variation in voluntary feed intake (VFI) accounts for 50% of the variation in feeding value of forages (Ulyatt 1973). As a consequence, any characteristics of the feed which affect intake and the ease of harvesting are critical to the value of the feed for animal production. A number of physical and chemical factors determine both actual intake and utilisation.

Accessibility

The growth architecture of acacia trees and shrubs is likely to limit access by grazing ruminants. Animals can increase intake rate to compensate partially for a reduction in bite size associated with browsing (for review see Ungar 1996), but usually small bite size cannot fully compensate for harvesting difficulties. However, litter fall from acacias (foliage plus fruit) can be as high as 7 tonne/ha/year, suggesting that the quality of litter should be assessed in any selection program. Management by seasonally controlling stocking rates, lopping, or cutting-and-carrying are options to increase fodder accessibility to the animal (Goodchild and McMeniman 1987).

Digestibility

Digestibility (dry matter digestibility, DMD) of forage is one of the measures used to describe the NV of forage. It is the proportion of the feed that is not excreted in the faeces and, although a simple method, large scale *in vivo* experiments are very expensive. Laboratory-based estimates of animal digestibility (*in vitro* dry matter digestibility IVD) are rapid and relatively inexpensive. Growth and production can be predicted by using digestibility, to calculate megajoules (MJ) of metabolisable energy (ME) per kg feed dry matter (M/D) (Standing Committee on Agriculture 1990).

The IVD of acacia foliage has been determined for only a small percentage of the Australian species but available data indicate that it is relatively low, ranging from 28.9% to 55.0%. The lower values have been recorded for the phyllodinous species (Gohl 1981; McDonald and Ternouth 1979; McLeod 1973; McMeniman *et al.* 1981; Skerman 1977; Vercoe 1986; Craig *et al.* 1991). This relatively low DMD is probably associated with the high lignin content of the cell wall; fibre digestibility is inversely related to lignin content of the fibre (Van Soest 1982). Craig *et al.* (1991) found that digestibility differed between shoots and phyllodes as well as with season and that these differences varied between species.

Where forages have low digestibility, low metabolisable energy and high fibre values, then theoretically a grazing animal can still grow by increasing intake. In reality, when IVD falls below 55%, physical limitations on the rate of eating, rate of digestion and passage through the gastrointestinal tract mean that intake is restricted and live weight loss is inevitable (calculated from Standing Committee on Agriculture, 1990).

Mulga is the only Australian acacia so far subjected to detailed *in vivo* digestibility studies in Australia, although *Acacia saligna* has been studied extensively overseas. Mulga has an *in vivo* digestibility of 39-64.5% (Gartner and Niven 1978; Goodchild and McMeniman 1987; Pritchard *et al.* 1992), suggesting scope for selection of lines suitable for animal production.

Digestibility can be improved by supplementation and ensiling. Digestibility of *A. aneura* was increased from 46.8 to 58.1% by the addition of phosphorus and molasses (McMeniman 1976). Prichard *et al.* (1992) showed a 3.4% increase in DMD but a change in nitrogen balance from -0.52 to 1.28 g/day with the use of polyethylene glycol and mineral supplement in the diet to reduce the influence of tannins on animal production. *Acacia saligna* is grown extensively overseas and animal studies have shown DMD ranging from 31.3% to 54.4% (Howard *et al.* 2001; Ben Salem *et al.* 1997; Abou El Nasr *et al.* 1996) with ensiling improving digestibility to 63.4% (Abou El Nasr *et al.* 1996). Australian studies by Howard *et al.* (2001), have reported the lowest digestibilities, 23.1% units lower than international studies, suggesting that there is a marked difference between the *A. saligna* accessions under study in animal experiments. Acacias grow in diverse environments, including salt affected areas so, when reviewing *in vivo* digestibility figures, consideration should be given to the soluble mineral content, the non-protein nitrogen and tannin content, as well as the traditional link between fibre content and digestibility. In areas where acacias will be utilised, however, supplementation and ensiling are unlikely to be cost effective and selection of suitable lines of acacias is required.

Studies of the Oxford *Gliricidia* collection showed large variation in both leaf *in vitro* DMD and nitrogen content in the 26 lines grown in the same environment (Schlink *et al.* 1991). Nitrogen content ranged from 3.00 to 4.15%, DMD from 67 to 80% and dry matter yield from 2.1 to 6.5 tonnes/ha with no relationship between dry matter yield and nutritional parameters. This poor correlation between plant yield and nutritional quality indicates that nutritional quality should be taken into account in the selection of species for animal usage.

Chemical composition

A selection of chemical compositions of Australian acacia species is presented in Table 1. Mineral concentrations also vary significantly between species, ranging from toxic to inadequate for livestock production. The ash in forage has no energy value but the apparent digestibility will be increased if the soluble ash content is high and not accounted for. Using DOMD (digestible organic matter in the feed dry matter) corrects for very high ash content; for example, hay with a 60% DMD has an DOMD of 55% whereas in a sample of *Atriplex* (salt bush: total ash 30%, soluble ash 24%) still with a digestibility of 60%, DOMD would now be 36% and ruminants would not be able to eat enough organic matter to prevent live weight loss (Masters *et al.* 2001).

Vercoe (1986) and Craig *et al.* (1991) reported phosphorus deficiencies in most acacias tested, leading to an imbalance in the calcium to phosphorus ratio in foliage (Table 2). Similarly, for most species the levels of potassium, sodium and sulphur were low (Vercoe 1986), but Craig *et al.* (1991) found that most acacias tested had adequate sodium levels. In the latter case, differences between species should be treated with caution, as the plant material was collected from the wild. Such differences may reflect differences in soil and growing conditions more than differences between species. In a study of the mineral composition of foliage of some species of *Acacia*, Vercoe

TABLE 1
Proximal composition of leaves of some commonly grazed species of *Acacia* (extracted from: Goodchild and McMeniman 1987; Craig *et al*. 1991; Howard *et al*. 2001; Abou El Nasr *et al*. 1996; Degen *et al*. 2000; Kaitho *et al*. 1997; Salem *et al*. 1999).

SPECIES	CRUDE PROTEIN g/kg	ETHER EXTRACT tg/kg	CRUDE FIBRE g/kg	ASH g/kg	OMD *In vivo* g/g	OMD *in vivo* g/100 g	DMD *in vivo* g/100 g
A. aneura	92-203	21-56	238-366	34-69	35-63	35-50	
A. cambagei	109-133	31-59	137-159	110-140		44	
A. pendula	132-164		255-296	56-89	43	43-50	
A. farnesiana	150-242	20-60	100-223	44-78		54-68	
A. albida	171-197	15-30	124-215	64-86	53		
A. seyal	111-293	12-68	84-228	10-84			
A. ampliceps	120-170			110-150			50-55
A. brumalis	100-140			30-40			36-48
A. cyclops	80-100			60-100			39-44
A. ligustrina	90-120			40-60			44-52
A. saligna	50-150			80-140	31-60		

TABLE 2
Mineral composition of leaves of some species of *Acacia* (source: Vercoe 1986)

SPECIES	Ca (%)	P (%)	Na (%)	Mg (%)	S (%)	Zn (ppm)	Mn (ppm)
A. bidwillii	2.43	0.09	0.06	0.24	0.21	37	49
A. salicina	3.52	0.11	0.02	0.29	1.13	55	30
A. leptocarpa	.97	0.06	0.25	0.37	0.18	75	622
A. aneura	1.39	0.07	0.01	0.26	0.17	76	863
A. melanoxylon	0.81	0.09	0.16	0.28	0.16	64	457
A. deanei	0.70	0.09	0.09	0.27	0.15	37	64
A. concurrens	0.97	0.05	0.25	0.26	0.18	47	917
A. stenophylla	2.08	0.10	0.16	0.35	0.58	123	42
A. glaucocarpa	1.01	0.05	0.08	0.23	0.14	45	53
A. fimbriata	0.30	0.06	0.13	0.25	0.12	33	83

(1986) found that copper was at levels that may be toxic to sheep, but copper contamination of samples could not be ruled out. Other minerals (Table 2) were at acceptable levels.

Protein levels provided by plant analysis are often a misleading indication of protein available to animals consuming the plants. This is partly due to the methods used to determine protein in the plant and partly to the processing and absorption of protein and other nitrogen compounds in the ruminant gastrointestinal tract. Most acacias examined have adequate crude protein contents for animal production. Again, there is considerable variation between species, ranging from 5.0% to 29.3% (Table 1).

An effective selection process will require screening a very large number of samples to determine plant quality. Near infrared reflectance spectroscopy (NIR) is a rapid, inexpensive and accurate method, requiring only small samples of plant material. NIR requires calibration with actual wet chemistry results from a subset of samples.

Pods and seeds

In general, pods have lower crude protein concentration and higher organic matter digestibility than foliage (Gohl 1981). In Australia and internationally there are few reports of the nutritional value of acacia pods and seeds for livestock despite the extensive knowledge of the use of acacias for human consumption and widespread consumption of ripe pods by animals in the dry season. In many areas, fruits are collected and brought to feed cattle or sheep or sold for fodder. In some regions animals are taken to the trees and fruit is consumed as it falls naturally or is knocked down by herders. In the semi-arid grazing regions of Australia *A. aneura* pods are much sought after by sheep, either on the trees or after they have ripened and fallen (Everist 1969). A number of other Australian acacias have been identified as being sought after by livestock (Maslin *et al.* 1998).

The fruits from *A. tortilis*, *A. albida*, *A. nilotica* and *A. sieberiana* have been evaluated in comparison with more traditional extracted protein meals (Tanner *et al.* 1990).

In general, *A. tortilis* and *A. albida* appear to have a nutritive value comparative to that of the extracted protein meal when offered as a supplement to maize stover. Lower growth rates and feed intakes occurred with *A. sieberiana* and *A. nilotica*, which the authors attributed to the phenolic compound and proanthocynidins in the fruit. The extent of digestion of the seed in the fruits ranged from 54% for *A. tortilis* to 96% for *A. sieberiana*. Ingestion and passage of seed through the digestive tract and subsequent appearance in the faeces permits seed distribution and improved seed germination (Gwynne 1969). Low apparent digestion of *A. tortilis* seeds would mean a significant loss of potentially available nitrogen and energy to the animal but effective spread of the seeds. Lowry *et al.* (1993) found that *A. nilotica* fruit used as a supplement on dry Mitchell Grass hay stimulated the intake of hay while the sheep remained in negative nitrogen balance. Improved nutritional status with fruit supplementation had positive effects on both live weight and wool growth.

Cleaned seed has been proposed for human consumption and extensive studies of the composition have been undertaken of a number of acacia species (Brand and Maggiore 1991; Rivett *et al.* 1983). A number of species have been identified for potential commercial production for human consumption (Simpson and Chudleigh 2001). Although the emphasis in these studies has been on the potential for human consumption, the possibility of livestock utilisation should not be overlooked. Simpson and Chudleigh (2001) determined that harvesting technology may pose an economic constraint on the human-food industry, particularly in the early phase of establishing the industry. Livestock can self-harvest seed that may be uneconomic to harvest in the early stages of plantation and technology development, thus providing an economic return beyond that obtained from the harvested product alone.

Secondary compounds

Plants growing in inhospitable environments frequently contain secondary compounds that play a role in plant survival. Secondary compounds may function to enable the plant to tolerate the soil, water and climatic stress or may act as deterrents to grazing herbivores (e.g. tannin, oxalate, nitrates). Acacias are reported as having a wide range of secondary compounds apart from tannins, summarised in Table 3.

Tannins

Tannins are polyphenolic compounds found in many plants and are by far the most common secondary compound found in acacias of Australia. Tannins can be beneficial or detrimental to the ruminant, depending on concentration. From 2-4 % tannins in the diet protects protein from rumen degradation and increases the absorption of essential amino acids whereas 4-10% depresses voluntary feed intake (VFI) (Terrill *et al.* 1992; Barry and McNabb 1999). Benefits reported include increases in wool production, milk protein secretion, ovulation rate and the development of more nutritionally based and ecologically sustainable systems for disease

TABLE 3
Toxic compounds in *Acacia* species for ruminants.

SPECIES	PART OF PLANT	TOXIN	REFERENCE
A. aneura	phyllode	oxalate	Gartner and Hurwood 1976
A. aneura	phyllode	tannin	
A. burrowii	flowers	hydrogen cyanide	Cunningham *et al.* 1981
A. cambagei	phyllode	hydrogen cyanide	
A. cambagei	timber, bark	oxalate	
A. cana	browse	selenium	
A. deanei	browse	hydrogen cyanide	
A. decora	browse	abortive agent	
A. doratoxylon	browse	cyanogenic glycoside	
A. georgina	browse	hyrolytic enzyme only	Hall 1972
A. georgina	seeds/pods	fluoroacetate	Everist 1969
A. giraffae	unripe pods	unknown toxin	Gohl 1981
A. implexa	unripe pods	unknown toxin	Cunningham *et al.* 1981
A. longifolia	browse	hydrogen cyanide	
A. murrayana	browse	unknown toxin	
A. paradoxa	browse	unknown toxin	
A. salicina	phyllode/bark	tannin	Hall 1972
A. salicina	pods	saponin	Hall 1972
A. saligna	browse/pods	tannins	Degen *et al.* 1998
A. berlandieri	browse	amines and alkaloids	Clements *et al.* 1997
46 *Acacia* spp.	foliage	hydrogen cyanide	Maslin *et al.* 1986

control in grazing animals. Tannins may also appear to have some protective effects against the establishment of, and tissue damage caused by, gastrointestinal nematodes (Kahn and Diaz-Hernandez 2000). Tannins levels in excess of 50 g/kg dry matter, on the other hand, can lead to low palatability, reduce digestibility, lower intake, inhibit digestive enzymes and be toxic to rumen micro-organisms (Kumar and Vaithiyanathan 1990). The availability of sulphur and iron also becomes limiting to animals consuming tannin-rich foliage. Sheep ingesting 0.9g hydrolysable tannins per kg body weight can show signs of toxicity in 15 days. Animals such as mule deer, rats and mice have been shown to secrete proline-rich proteins in saliva and these constitute the first line of defence against ingested tannin. Unfortunately, the proline-rich protein defence is not present in domestic ruminant species to enable domestic livestock to consume plants high in tannins.

Oxalates

Oxalates cause precipitation of insoluble calcium oxalate in the rumen and kidneys, resulting in kidney damage, rumen stasis, gastroenteritis, calcium deficiency and possible death. Poisoning in sheep and cattle has been reported when pasture contains 7-8% oxalate (Hungerford 1990). Voluntary feed intake is significantly depressed by 3% oxalates (Burritt and Provenza 2000) and may contribute to the observed low intakes of acacia.

Nitrate

Nitrates are converted to nitrites in the rumen and, following absorption, result in the conversion of haemoglobin to methaemoglobin. Methaemoglobin is unable to bind oxygen and causes anoxia accompanied by increased pulse and respiration rates. As with oxalates, high nitrates also result in depressed feed intake. Toxic levels of nitrogen as nitrate are above 5000 mg N/kg DM in the diet (National Research Council 1974), 8000 mg N/kg DM reduces feed intake in the sheep by over 60% (Burritt and Provenza 2000).

Oxalate, fluoroacetate and hydrogen cyanide are well-recognised toxins to livestock (Barry and Blaney 1987). These compounds should be identified early in the evaluation of plants for animal production and only species or provenances with low levels should be considered for further evaluation for nutritional potential. A similar situation applies for amines and alkaloids in plant material. Where these compounds exist in plants within current grazing systems then animal management strategies must be put into place to minimise the impact of secondary compounds on animal production.

Reducing the impact of secondary compounds

There has been a heavy dependence on *A. aneura* as a drought feed in the semi-arid grazing areas of Australia. *A. aneura* contains both tannins and oxalates that result in a feed source with poor animal production despite its favourable concentrations of crude protein. Attempts have been made over a number of years to develop strategies to improve the value of this feed source because in some situations, for example drought, it is the only feed available.

Pritchard *et al.* (1992) showed that dosing sheep with polyethylene glycol (PEG) increased both intake and wool production in sheep fed with *A. aneura*. The sheep both retained and digested more nitrogen and sulphur than sheep supplemented with non-PEG. Economically, supplementation with PEG may not be viable.

Alternative but less efficient methods of improving digestion of *A. aneura* have also been developed for grazing ruminants. Supplementation of sheep with molasses increased intake and dry matter digestibility of *A. aneura* (Entwistle and Baird 1976; McMeniman 1976). Hoey *et al.* (1976) showed that the molasses response was due mainly to the sulphur content of molasses. Molasses is overcoming a likely tannin-induced sulphur deficiency in the rumen, leading to improved microbial activity in the rumen and thence to improved rumen fermentation and feed intake. Increases in intake and live weight gain can also be achieved by using 50 g/day.head of cottonseed meal to provide additional protein and sulphur (McMeniman *et al.* 1981). These responses have been confirmed in grazing experiments where *A. aneura* supplemented with molasses (or sulphur), phosphorus and protein meal has improved live weight responses, wool growth and reproductive performance compared to non-supplemented sheep (McMeniman and Little 1974; Niven and McMeniman 1983).

Overseas, extensive studies have also been carried out with *A.saligna* to improve its utilisation by ruminant livestock. Utilisation of PEG to improve the nutritional value of *A. saligna* by increasing intake, nitrogen retention, microbial nitrogen yield and daily gain has been achieved compared with the performance of non-supplemented sheep consuming *A. saligna* (Ben Salem *et al.* 2000). This study used PEG in supplementation blocks to improve the effective utilisation of tannin-rich acacias, in contrast to other studies that used more intensive means to apply the PEG.

The most economically viable strategy for using acacias may be to select for lower levels of secondary compounds and to include other plants in a mixed grazing system. Natural variation within a species has been exploited extensively in agriculture to produce desirable outcomes. To improve the forage value of *Lotus corniculatus* (another forage legume), accessions have been selected with medium and low condensed tannin concentrations (Waghorn *et al.* 1987). As well as variation in secondary compounds within species there is also environmental variation. Tangendjaja *et al.* (1986) showed significant changes in minosine and flavonol glycosides with leaf age, whereas tannin concentration changes with soil fertility (Barry and Manley 1986), and season affects concentrations of both tannins and cyanogenic glucosides (Dement and Mooney 1974).

GRAZING SYSTEMS BASED ON *ACACIA*

Acacias can contribute to ruminant diets in several ways. Historically in Australia acacias have been browsed *in situ*, in the natural vegetation, usually as drought feed when the native pastures disappeared. Acacias may be utilised by browsing plants or litter and/or in a cut-and-carry system. One such species where a combination of the preceding options maybe applied is *A. aneura*. When conditions are severe enough and forage no longer available from standing trees, branches are lopped to provide *in situ* supplement for livestock, but *A. aneura* provides only a maintenance diet despite extensive efforts to reduce the nutritional impact of tannins (Goodchild and McMeniman 1987). A selection program to identify and exploit *A. aneura* trees which have naturally lower tannin levels may be the most cost-effective solution, with huge potential for animal production in semi-arid regions.

Predicting animal performance

Once plant quality characteristics of selected acacias have been estimated, the nutritional management program for ruminants GrazFeed (Freer *et al.* 1997) may be used to estimate potential animal performance. For example, weaner wethers grazing acacia foliage and pods with an estimated digestibility of 47% and protein content of 9% are predicted to lose 80 g of live weight per day. Weaners offered this combination with dead pasture (51% digestibility) were estimated to have a modest weight gain (13 g/day), due to increased capacity to select higher quality components in the diet. However if acacia species/composition resulted in a digestibility of 55% and protein content of 11% then weaners could maintain live weight with an intake of 900 g/day of acacias alone. These predictions would require validation by animal feeding before recommendations could be made since no account of secondary compounds or limitations to forage acquisition is included in these estimates.

CONCLUSIONS

Utilisation of acacia in farming systems could be improved through selection, which will establish and provide feed for livestock during feed gaps and droughts, provided that issues of fodder accessibility and secondary compounds are overcome. Successful selection will require simultaneous determination of the critical levels of nutritional and anti-nutritional factors for ruminants and validation in feeding studies. The results would then be used for the selection of potentially useful plants, which is likely to be more cost-effective than nutritional interventions to overcome the effects of secondary compounds. Australia has a large proportion of the world's acacia species. To date, their potential for animal production has not been studied in any systematic fashion, despite their extensive use in periods of nutritional stress.

REFERENCES

Abou El Nasr, H.M., Kandil, H.M., El Kerdawy, A., Dawlat, Khamis, H.S. and El-Shaer, H.M. (1996). Value of processed saltbush and acacia shrubs as sheep fodders under the arid conditions of Egypt. *Small Ruminant Research* **24**, 15-20.

Allden, W.G. and Whittaker, I.A.M. (1970). The determinants of herbage intake by grazing sheep; the interrelationship of factors influencing herbage intake and availability. *Australian Journal of Agricultural Research* **21**, 755-766.

Barry, T.N. and Blaney, B.J. (1987). Secondary compounds of forage. In *The Nutrition Of Herbivores* (J.B.Hacker and J.H.Ternouth, eds), pp. 91-119. Academic Press, Marrickville, N.S.W.

Barry, T.N. and Manley, T.R. (1986). Interrelationships between the concentrations of total condensed tannins, free condensed tannin and lignin in *Lotus* sp. and their possible consequences in ruminant nutrition. *Journal of Science, Food and Agriculture* **37**, 248-254.

Barry, T.N. and McNabb, W.C. (1999). The implications of condensed tannins on the nutritive value of temperate forages fed to ruminants. *British Journal of Nutrition* **81**, 263-272.

Ben Salem, H., Nefzaoui, A., Ben Salem, L., Ferchichi, H. and Tisserand, J.L. (1997). Intake and digestion in sheep given fresh or air-dried *Acacia cyanophylla* Lindl. foliage. *Annules de Zootechnie* **46**, 361-374.

Ben Salem, H., Nefzaoui, A., Ben Salem, L., Ferchichi, H. and Tisserand, J.L. (2000). Deactivation of condensed tannins in *Acacia cyanophylla* Lindl. foliage by polyethylene glycol in feed blocks. Effect on feed intake, diet digestibility, nitrogen balance, microbial synthesis and growth by sheep. *Livestock Production Science* **64**, 51-60.

Bhattachrya, A.N. (1989). Nutrient utilization of acacia, haloxylon and atriplex species by Najdi sheep. *Journal of Range Management* **42**, 28-31.

Brand, J. and Maggiore, P. (1991). The nutritional composition of Australian Acacia seeds. In *Australian Dry-zone Acacias for Human Food* (A.P.N.House and C.E.Harwood, eds), pp. 54-67. Proceedings of a workshop held at Glen Helen, Northern Territory, 7-10 August 1991. Division of Forestry, CSIRO, Canberra.

Burritt, E.A. and Provenza, F.D. (2000). Role of toxins in intake of varied diets by sheep. *Journal of Chemical Ecology* **26**, 1991-2005.

Chippendale, G.M. and Jephcott, B.R. (1963). *Topfeed.* Extension Article no. 5, Animal Industry Branch, Northern Territory Administration, Alice Springs.

Clement, B.A., Goff, C.M. and Forbes, T.D.A. (1997). Toxic amines and alkaloids from *Acacia berlandieri*. *Phytochemistry* **46**, 249-254.

Craig, G.F., Bell, D.T. and Atkins, C.A. (1991). Nutritional characteristics of selected species of *Acacia* growing in naturally saline areas of Western Australia. *Australian Journal of Experimental Agriculture* **31**, 341-345.

Cunningham, G.M., Mulham, W.E., Milthorpe, P.L. and Leigh, J.H. (1981). *Plants of Western New South Wales.* Soil Conservation Service of N.S.W. and N.S.W. Government Printing Office, [no loc.].

Degen, A.A., Mishorr, T., Makkar, H.P.S., Kam, M., Benjamin, R.W., Becker, K. and Schwartz, H.J. (1998). Effect of *Acacia saligna* with and without administration of polyethylene glycol on dietary intake in desert sheep. *Animal Science* **67**, 491-498.

Degen, A.A., Benjamin, R.W., Mishorr, T., Kam, M., Becker, K., Makkar, H.P.S. and Schwartz, H.J. (2000). *Acacia saligna* as a supplementary feed for grazing desert sheep and goats. *Journal of Agricultural Science* **135**, 77-84.

Dement W.A. and Mooney, H.A. (1974). Seasonal variation in the production of tannins and cyanogenic glucosides in the chaparral shrub, *Heteromeles arbutifolia*. *Oecologia* **15**, 65-76.

Everist, S.L. (1969). *Use of Fodder Trees and Shrubs.* Queensland Department of Primary Industries Advisory Leaflet no. 1024.

Entwistle, K.W. and Baird, D.A. (1976). Studies on the supplementary feeding of sheep consuming mulga (*Acacia aneura*), 2, Comparative levels of molasses and urea supplements fed under pen conditions. *Australian Journal of Experimental Agriculture and Animal Husbandry* **16**, 174-180.

Freer, M., Moore, A.D. and Donnelly, J.R. (1997). GRAZPLAN: decision support systems for Australian enterprises, II, The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems* **54**, 77-126.

Gartner, R.J.W. and Hurwood, I.S. (1976). The tannin and oxalic acid content of *Acacia aneura* (mulga) and their possible effects on suphur and calcium availability. *Australian Veterinary Journal* **52**, 194-195.

Gartner, R.J.W. and Niven, D.R. (1978). Studies on the supplementary feeding of sheep consuming mulga (*Acacia aneura*) 4. Effect of sulphur on intake and digestibility, and growth and sulphur content of wool. *Australian Journal of Experimental Agriculture and Animal Husbandry* **18**, 768-772.

Gohl, B. (1981). *Tropical Feeds.* Food and Agriculture Organisation, Rome.

Goodchild, A.V. and McMeniman, N.P. (1987). Nutritive value of *Acacia* foliage and pods for animal feeding. In *Australian Acacias in Developing Countries*, Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld, Australia, 4-7 August 1986 (J.W.Turnbull, ed.), pp. 101-106. ACIAR Proceedings no. 16, Australian Centre for International Agricultural Research, Canberra.

Gwynne, M.D. (1969). The nutritive values of *Acacia* pods in relation to *Acacia* seed distribution by ungulates. *East African Wildlife Journal* 7, 176-178.

Hall, N. (1972). *The Use of Trees and Shrubs in the Dry Country of Australia.* Australian Government Printer, Canberra.

Hall, W.B., Rickert, K.G., McKeon, G.M. and Carter, J.O. (2000). Simulation studies of nitrogen concentration in the diet of sheep grazing Mitchell and mulga grassland in western Queensland. *Australian Journal of Agricultural Research* **51**, 163-172.

Hoey, W.A., Norton, B.W. and Entwistle, K.W. (1976). Preliminary investigations with molasses and sulphur supplementation of sheep fed mulga (*Acacia aneura*). *Proceedings of the Australian Society of Animal Production* **11**, 377-380.

Hungerford, T.G. (1990). *Diseases of Livestock*, 9th edn. McGraw-Hill Book Company, Sydney.

Kahn, L. P. and Diaz-Hernandez, A. (2000). Tannins with anthelmintic properties. In *Tannins in Livestock and Human Nutrition* (J.D.Brooker, ed.), pp. 130-139. Proceedings no. 92, Australian Centre for International Agricultural Research, Canberra.

Kaitho, R.G., Umunna, N.N., Nashlai, I.V., Tamminga, S., Van Bruchem, J. and Hanson, J. (1997). Palatability of wilted and dried multipurpose tree species fed to sheep and goats. *Animal Feed Science and Technology* **65**, 151-163.

Kumar, R. and Vaithiyanathan, S. (1990). Occurrence, nutritional significance and effect on animal productivity of tannins in tree leaves. *Animal Feed Science and Technology* **30**, 21-38.

Lefroy, E.C., Dann, P.R., Wildin, J.H., Wesley-Smith, R.N. and McGowan, A.A. (1992). Trees and shrubs as sources of fodder in Australia. *Agroforestry Systems* **20**, 117-139.

Lowry, J.B., Schlink, A.C. and Carter, J.O. (1993) *Nutritive Value of* Acacia nilotica *for Sheep in Mitchell Grass Pasture.* Australian Wool Research and Development Corporation Final Report, Project CS108P.

Maslin, B.R., Conn, E.E. and Dunn, J.E. (1986). Cyanogenic Australian species of *Acacia*: a preliminary account of their toxicity potential. *Australian Acacias in Developing Countries*, Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld, Australia, 4-7 August 1986 (J.W.Turnbull, ed.), pp. 107-111. ACIAR Proceedings no. 16, Australian Centre for International Agricultural Research, Canberra.

Maslin, B.R., Thompson, L.A.J., McDonald, M.W. and Hamilton-Brown, S. (1998). *Edible Wattle Seeds of Southern Australia: A Review of Species for Use in Semi-Arid Regions.* CSIRO Australia, Collingwood, and Department of Conservation and Land Management, Como.

Masters, D.G., Norman, H.C. and Dynes, R.A. (2001). Opportunities and limitations for animal production from saline land. *Asian-Australian Journal of Animal Science* **14**, 199-211.

McDonald, W.J.F. and Ternouth, J.H. (1979). Laboratory analysis of the nutritional value of western Queensland browse feeds. *Australian Journal of Experimental Agriculture and Animal Husbandry* **19**, 344-349.

McLeod, M.N. (1973). The digestibility and the nitrogen, phosphorus and ash contents of the leaves of some Australian trees and shrubs. *Australian Journal of Experimental Agriculture and Animal Husbandry* **13**, 245-250.

McMeniman, N.P. (1976). Studies of the supplementary feeding of sheep mulga (*Acacia aneura*), 3, The provision of phosphorus, molasses and urea under pen conditions. *Australian Journal of Experimental Agriculture and Animal Husbandry* **13**, 245-250.

McMeniman, N.P. and Little, D.A. (1974). Studies on the supplementary feeding of sheep consuming mulga (*Acacia aneura*). *Australian Journal of Experimental Agriculture and Animal Husbandry* **14**, 316-321.

McMeniman, N.P., Niven, D.R., Crowther, D., Gartner, R.J.W. and Murphy, G.M. (1981). Studies on the supplementary feeding of sheep consuming mulga (*Acacia aneura*), 5, The effect of cobalt and cottonseed meal supplementation. *Australian Journal of Experimental Agriculture and Animal Husbandry* **21**, 404-409.

National Research Council (1974). *Nutrients and Toxic Substances in Water for Livestock and Poultry.* National Academy of Sciences, Washington, DC.

Niven, D.R. and McMeniman, N.P. (1983). Effects of mineral and protein supplements on sheep fed mulga under field conditions. *Queensland Journal of Agricultural and Animal Sciences* 40, 67-74.

Pritchard, D.A., Martin, P.R., and O'Rourke, P.K. (1992). The role of condensed tannins in the nutritional value of mulga (*Acacia aneura*) for sheep. *Australian Journal of Agricultural Research* **43**, 1739-1746.

Reed, J.D., Soller, H. and Woodward, A. (1990). Fodder trees and straw diets for sheep: intake growth, digestibility and effects of phenolics on nitrogen utilisation. *Animal Feed Science and Technology* **30**, 39-50.

Rivett, D.E. Tucker, D.J. and Jones, G.P. (1983). The chemical composition of seeds from some Australian plants. *Australian Journal of Agricultural Research* **34**, 427-432.

Salem, H.B., Nefzaoui, A., Salem, L.B., Tisserand, J.L., Ben Salem, H. and Ben Salem, L. (1999). Intake, digestibility, urinary excretion of purine derivatives and growth by sheep given fresh, air-dried or polyethylene glycol-treated foliage of *Acacia cyanophylla* Lindl. *Animal Feed Science and Technology* **78**, 297-311.

Schlink, A.C., Palmer, B. and Ibrahim, T. (1991). Variation in nitrogen content and digestibility in the 'Oxford' *Gliricidia* collection. *Proceedings of the Third International Symposium on the Nutrition of Herbivores, Penang, Malaysia, 25-30 August 1991* (M. Wan Zahari, ed.), pp. 61-62. MSAP, Selangor.

Simpson, S. and Chudleigh, P. (2001). *Wattle Seed Production in Low Rainfall Areas.* A report for RIRDC/Land & Water Australia. Publication no. 01/08, Forest Wood Products Research and Development Corporation/Rural Industries Research and Development Corporation.

Skerman, P.J. (1977). *Tropical Forage Legumes.* Food and Agriculture Organization, Rome.

Standing Committee on Agriculture (1990). *Feeding Standards for Australian Livestock.* CSIRO Publications, East Melbourne.

Tangendjaja, B., Lowry, J.B. and Wills, R.B.H. (1986). Changes in mimosine, phenol, protein and fibre content of *Leucaena leucocephala* leaf during growth and development. *Australian Journal of Experimental Agriculture* **26**, 315-317.

Tanner, J.C., Reed, J.D. and Owen, E. (1990). The nutritive value of fruits (pods and seeds) from four *Acacia* species compared with extracted noug (*Guizotia abyssinica*) meal as supplements to maize stover for Ethiopian highland sheep. *Animal Production* **51**, 127-133.

Terrill, T.H., Rowan, A.M., Douglas, G.B. and Barry, T.N. (1992). Determination of extractable and bound tannin concentrations in forage plants, protein concentrate meals and cereal grains. *Journal of Science, Food and Agriculture* **58**, 321-329.

Ulyatt, M.J. (1973). The feeding value of herbage. In *The Chemistry and Biochemistry of Herbage* (G.W.Butler and R.W.Bailey, eds), vol. 3, ch. 31, pp. 131-178. Academic Press, London and New York.

Ungar, E.D. (1996). Ingestive behaviour. In *The Ecology and Management of Grazing Systems* (J.Hodgson and A.W.Illius, eds), pp. 185-218. CAB International, Wallingford.

Van Soest, P.J. (1982). *Nutritional Ecology of the Ruminant.* O & B Books, Corvallis, Oregon.

Vercoe, T.K. (1986). Fodder potential of selected Australian tree species. In *Australian Acacias in Developing Countries,* Proceedings of an international workshop held at the Forestry Training Centre, Gympie, Qld, Australia, 4-7 August 1986 (J.W.Turnbull, ed.), pp. 95-100. ACIAR Proceedings no. 16, Australian Centre for International Research, Canberra.

Waghorn, G.C., Ulyatt, M.J., John, A. and Fisher, M.T. (1987). The effect of condensed tannins on the site of digestion of animo acids and other nutrients in sheep fed on *Lotus corniculatus* L. *British Journal of Nutrition* **57**, 115-126.