Nutritive value of browses as protein supplement(s) to poor quality roughages

Promotoren: **dr. Ir. S. Tamminga**
Hoogleraar op het vakgebied van de veevoeding in het bijzonder de voeding van herkauwers.

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Statements

1. Given that animals can adapt to feeds with time, at least 5-8 days should be allowed in palatability trials.
   (This thesis)

2. Using chemical composition, *in vitro* degradability or gas production characteristics are inadequate for ranking browses.
   (This thesis)

3. Tannins posses detrimental effects at high levels but in ruminants have beneficial attributes at low levels.
   (This thesis)

4. Long-term studies of browse supplementation are necessary as some of the browses' negative effects are only observed in long-term feeding trials.
   (This thesis)

5. Goats are without peer in terms of using unimproved pasture and range areas with low quality vegetation.
   (This thesis)
   Ensminger M.E. and Olentine C.G. 1978. Feeds and Nutrition. The Ensminger Publishing Company, Clovis, California, USA.

6. Knowledge of behavioural norms is necessary in order to detect and treat abnormality. From: The Bettmann archive.

7. For thousands of years, the quest for food has shaped the course of history.

8. Taste as beauty is in the eyes of the beholder.

9. Ruminants spend too much of their time eating - in consuming feed and chewing their cud.

10. Searching for specific information from the internet is very easy if you know how to browse. Have a browsing day, Won't you!

Robert J. Kaitho
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Wageningen, 2 September 1997.

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Robert J. Kaitho

Proefschrift

ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van de Landbouwuniversiteit te Wageningen,
dr C.M. Karssen,
in het openbaar te verdedigen
op dinsdag 2 september 1997
des morgens te elf uur in de Aula.

CIP-DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Kaitho, R.J.

Nutritive value of browses as protein supplement(s) to poor quality roughages / R.J. Kaitho. -[S.l. :s.n.]
Thesis Landbouw Universiteit Wageningen. - With ref. - With summary in Dutch.
ISBN 90-5485-735-8
Subject heading: Nutritive value, browse

Kaitho, R.J. 1997. Nutritive value of browses as protein supplement(s) to poor quality roughages. In tropical and subtropical regions, pasture grasses and cereal residues are frequently low in nutrients especially protein and therefore cannot support high levels of ruminant production. Many browse species are endowed with high levels of protein and hence suitable as supplements. The objective of this study was to develop indices that could be used to predict nutritive value of browses as supplements to poor quality roughage basal diets. Experiments were carried out to address issues related to establishing an experimental protocol for screening large browse species in feeding trials, the effect of animal species and the proportion of browse in the diet. Different methods to estimate protein digestion in small intestine were compared and data of individual browses collected. The palatability method developed was suitable for evaluating palatability of large numbers of browses under stall feeding condition. If palatability is done to predict long term intake a period of 5 to 8 days should be allowed. Classification of browses using either chemical composition, degradability or gas production characteristics led to different cluster groups than when palatability was used. Tannins had beneficial attributes at moderate levels and detrimental effect at high levels. The optimum level of browse supplementation was 30 to 45% of the ration dry matter. Browses need to be further studied since some of the secondary chemicals contained may affect reproduction.
PhD Thesis, Department of Animal Nutrition, Wageningen Agricultural University, Marijkeweg 40, 6709 PG, Wageningen, the Netherlands.

This thesis is dedicated to my wife Esther.

Preface

I began this study at the International Livestock Research Institute (ILRI), Debre-Zeit Station, Ethiopia in October 1994. The aim of the study was to develop indices that could be used to predict nutritive value of browses as supplements to poor quality roughage basal diets. The study involved both animal trials and laboratory investigations, and was partly conducted in Ethiopia and in the Netherlands. Inevitably, the study called for participation of many individuals without whose help - financial, technical, logistical and moral - I would not have completed it.

I would like to express my deepest gratitude to International Livestock research Institute for financially supporting my research in Ethiopia. In particular I would like to thank the Director General Dr. H.A. Fitzhugh and Director of Training and information Dr. M. Smalley for their keen interest in my work as well as Dr. P. Osuji the project leader under which this research was carried out in Ethiopia. Working with Prof. N.N. Umunna, the station manager as my ILRI supervisor has been an enriching experience. His jovial nature, sense of humour and optimism, coupled with his experience and knowledge in animal nutrition will be something to remember always in my life. He is the supervisor I am proud to have. In the same vein, I am deeply indebted to Wageningen Agricultural University for offering me fellowship during my stay in Wageningen.

I would like to thank the Director of Kenya Agricultural Research Institute, Dr. C. Ndiritu for granting me study leave in order to pursue this study.

My promotor Prof. Seerp Tamminga and co-promoter Dr. Jaap van Bruchem have always shown great interest in the research and the write up. Their critical reading of the manuscripts and the draft thesis is greatly appreciated. Seerp's visit to Ethiopia to discuss with me experiments on the ground were very stimulating and encouraging. I highly appreciate the kindness with which he attended my numerous administrative problems.

I am very much obliged to Dr. Ignatius V. Nsahlai my crony and co-supervisor. His personal interest in this study, encouragement, guidance, patience and kindness made it possible for me to complete the task. During the write up of the papers which make up this thesis Ignatius was always very keen to read and discuss the manuscripts. His numerous suggestions are highly appreciated and in times of difficulties, his encouraging remarks made life bearable. He was a friend indeed. I would also like to thank P. Snijders and S. Schukking for their contribution to my work over time and also for the effort they put in translating the summary.

During my palatability experiments in Zwai, Ethiopia I got a lot of assistance, materially and logistically from Dr. J. Hanson, M. van der Wouw, J. Mohammed and L. Makore for which I am indeed grateful. I would like to express my appreciation to the staff of ILRI Debre-Zeit station especially those who were working in the sheep barn such as Olga, Deguso, Kabende and Kasahun. I'm grateful to Abera Addie, Amare Feleke and Telahun for their contribution to my work. I am also heavily indebted to my "Tukulmates" who made sure I felt at home during my stay in Debre-Zeit, especially Denis, Wame (B2), Azeb and Workineh. I would also like to express my appreciation to the staff of the Department of Animal Nutrition, Wageningen for their contribution to my work at all stages and Mebratu Ogbai and Nutrition laboratory staff, Addis Ababa for their help during laboratory analysis.

Finally, I would like to thank my father Mr. Kaitho Wanzuu and mum for their inspiration and support during my school life. Last but not least is my measureless gratitude and loving thanks to my wife Ms. Esther and our children Alice, Paul and Samuel for their endurance, moral support and patience which enabled me successfully complete this study. To you all I say "*Asante sana*" and may God bless you.

CONTENTS

General Introduction

Intake of poor quality pasture grasses and cereal straws by ruminants is usually low to maintain body weight because of their tough texture, poor digestibility and nutrient deficiency which contribute to the low level of consumption (El-Naga, 1989). These roughages are deficient in readily available energy and nitrogen, which reduces the efficiency with which they are utilized by animals. Most of these deficiencies can be corrected by supplementation with high density feeds such as oilseed cakes. However, protein sources such as oil seed cakes and those of animal origin are produced in limited quantities and are often beyond the economic reach of most farmers.

Fortunately a large number of legumes have been documented as useful livestock fodder. The main features of forage legumes are their high crude protein and mineral content. The concentration of crude protein in the leaves and fruits of the majority of browses is above 10% even in the dry season when it tends to decrease. Browse has been defined as the leaves, shoots and sprouts including tender twigs and stems of woody plants which are cropped to a varying extent by domestic and wild animals (Gutteridge and Shelton, 1994). It should be extended to include the fruits, pods and seeds which provide valuable feed, especially if the tree is deciduous.

Compared to herbaceous legumes, browse legumes are easy to establish and sustain and therefore ecologically more appropriate. Along with diversity in size, there is a range of agronomic characteristics which have enabled establishment and growth to occur in different agro-ecological zones. Browses have provided valuable forage to man's herbivorous animals probably since the time of their domestication (Robinson, 1985). At least 75% of the trees and shrubs of Africa serve as browse plants and many of these are leguminous. McKell (1980) pointed out that shrubs and trees are the most visible plant forms in many landscapes, yet have been neglected in most scientific research.

Browses have multiple roles in farming systems, as animal feed, firewood, mulch and soil conservation and improvement. If their foliage can be shown to increase livestock performance when fed in conjunction with low quality roughages, farmers would have another reason to grow browses alongside their crops. The beneficial effect of feeding browses to the animal include increased metabolizable energy intake, increased nitrogen intake, better animal performance and feed efficiency, improved palatability, increased availability of minerals and vitamins, improved rumen function and a laxative influence on the alimentary system. An important attendant advantage is a lowered cost of feeding due to a reduced dependence on purchased energy and protein supplements.

Improvement in animal productivity requires improved nutrition throughout the year with a guarantee for adequate supply, quantitatively and qualitatively. Forage from browses is often used as a buffer to overcome feed gaps that arise from seasonal

fluctuations in the productivity of other fodder resources. For example, grasses and other herbs may die when the upper soil layers lose their moisture but the deep-rooted trees exploit moisture at depth and continue to grow. During the dry season or in times of drought, trees provide green feed that is rich in protein, minerals and vitamins while the herbaceous cover provide only poor quality straw.

Many browse species have co-evolved with predator populations of bacteria, insects, fungi and grazing animals and thus have developed defence mechanisms for survival. Despite their high nitrogen content, they often have thorns, fibrous foliage and growth habits which protect the growing points. Many of them also produce chemicals (secondary compounds) which are not directly involved in the process of plant growth, but act as deterrents to insect and fungal attack (Brewbaker, 1986). These secondary compounds may produce toxic effects in animals (eg. cyanide, fluoro-acetate), may depress intake and/or utilization of feed components (high tannin content), or may enhance feed nutritive value (low tannins, anti-protozoa property). Phenolic compounds (tannins) are widespread, abundant and appear to be the major constraint of browses as forages because of their effect on intake, digestibility and animal metabolism.

Nutritive value of a feed is a function of the feed intake, the efficiency of extraction of nutrients from the feed during digestion and the efficiency of utilization of the extracted nutrients. Feeds of high nutritive value promote high levels of production (live weight gain, milk production). Feed intake in ruminants consuming fibrous forages is primarily determined by the level of rumen fill, which in turn, is directly related to the rate of digestion and passage of fibrous particles from the rumen. Voluntary consumption of a feed is known to be modified by animal preference, and this is of particular interest in browses because acceptability or edibility (palatability) of a feed has been related to both physical characteristics (hairiness and bulk density) and the presence of secondary compounds (volatile oils, tannins) which may affect taste and appetite.

There is high variability in the nutrient content of browses attributed to within and between species differences due to factors such as plant age, plant part, harvesting regimen, season and location. There is no simple predictor of the quality of browse foliage, as chemical composition alone is an inadequate indicator of nutritive value. Therefore, the main objective of this study was to develop indices that could be used to predict nutritive value of browses as supplements to poor quality roughage basal diets. In an attempt to develop the indices, issues related to establishing an experimental protocol for screening large browse species in feeding trials, the choice of animal species to be used in these trials and the proportion of browse in the diet were addressed.

The more specific objectives were:

1. To develop a palatability index which combines palatability and intake and

determine the effect of length of study on accuracy of browse palatability ranking. Based on the results of the palatability study, a sub-objective was developed to determine the effect of animal species and browse form (dry or wilted) of presentation on palatability.

2. To determine inter-relationships among palatability and chemical composition, gas production and rumen degradation parameters in order to find out which among the procedures could predict palatability and thus intake.
3. To estimate by the mobile bag technique and pepsin/pancreatin method, intestinal digestibility of browse rumen undegraded protein.
4. To determine the nutrient release and utilization patterns when animals are supplemented with browses having varying chemical attributes.
5. To determine the long term effect of browse supplementation on growth and reproductive performance.
6. To determine the effects of feeding graded levels of different fodder trees on intake and utilization of teff (*Eragrostis tef*) straw.

Outline of the thesis

This thesis describes the nutritive value of browses as supplements to poor quality roughages. In Chapter 1, browse utilization and constraints to their efficient utilization was reviewed. The focus of this review was on nutritive value, chemical composition, voluntary intake and limitations of browse as a sole feed. The use of browses as supplement to poor quality roughages (live weight gain and milk production) and the limitations imposed by the presence of anti-nutritional factors were emphasized. Chapter 2 described a method of determining palatability of a large number of browses and the appropriate length of study on intake and relative palatability ranking. The effects of browse form (wilted or dried) of presentation and animal species (sheep and goats) on palatability indices were determined in Chapter 3. In Chapter 4, the interrelationships between palatability, gas production, degradability coefficients and chemical composition attributes were discussed. Browses are good protein supplements for ruminants and are an integral part of many agricultural systems. The nitrogen degradability and digestibility of the rumen undegradable nitrogen using nylon bag technique and pepsin/pancreatin *in vitro* method was determined in Chapter 5. Subsequently, in Chapters 6 and 7, the nutritive value of browse supplements with varying tannin levels was evaluated in sheep. In Chapter 8, the long term effect of supplementation of browses on growth and reproduction performance of sheep and goats was determined. The effect of feeding graded levels of browse supplements on intake, digestibility and live weight changes were evaluated in Chapter 9. In the general

discussion (Chapter 10), results of the experiments were discussed and related to current knowledge on nutritive value of browses.

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Chapter 1

Browses: utilization and the constraints to their utilization

Browses: utilization and the constraints to their utilization

Introduction

Projected increase in human population throughout the developing world and the limited availability of land for increased food and forage production suggest that agricultural production will need to be intensified considerably if current human and animal nutritional standards are to be maintained. In many of the ruminant-production systems in the developing world, native or natural pastures make up the bulk of feed. The low quality and the seasonal nature of the forage supply, together with the low intake by the animals and the poor digestibility of the forage, are major factors contributing to the low productivity of ruminant animals (Remenyi and McWilliam, 1986). The need is not for forages alone, but for forages available on the farm and whose economic implications can be met by farmers.

Attempts have been made to improve the nutritive value of low quality roughages through treatment with chemicals (Adebowale et al., 1989; Ørskov, 1989), enzymes (Al-Saghier and Campling, 1991), by supplementation with urea (Umunna et al., 1982) protein nitrogen and energy sources (Alawa et al., 1987; Silva and Ørskov, 1988; Steen, 1989; Al-Saghier and Campling, 1991) and by genetic selection (Tuah et al., 1986, Bainton et al., 1987; Ørskov, 1989). Conventional protein supplements and chemical treatments of roughages may not be practical or economical in most tropical countries (Mero and Uden, 1990), because conventional supplements are expensive and out of reach of many farmers.

Trees and shrubs (browse) are a group of feed supplements that are currently not fully exploited in livestock feeding especially in the smallholder systems, because the mode of utilization has not been fully understood. The term browse is defined to refer to the tender shoots and twigs of shrubs and woody plants, and also fruits and pods. They form an important component of the diet, especially for a variety of herbivores, and have been used traditionally as sources of fodder for domesticated livestock in Asia, Africa and the Pacific (Skerman, 1977; NAS, 1979; Le Houérou, 1980a). Browse legumes are found in all areas, but within the prevailing ecosystems from arid to highland areas, browse becomes increasingly more important in the arid and semiarid environments where inadequate feeds are a major constraint for survival and production of animals.

Browse legumes are more important than simply being a source of feeds. In many situations, they form part of complex interactions between plants, animals and crops, the positive aspects of which help to balance a plant-animal-soil ecosystem, and from which there is a sustainable source of feeds.The foliages of some are used as

vegetables by humans while the roots, bark or stem and leaves of others are used for medicinal purposes. In ruminant nutrition they provide rumen degradable nitrogen and/or by-pass nitrogen, digestible energy and minerals when used as either supplements or as sole feed (Ash, 1990; Kaitho, 1992).

Browses have nutritional diversity in terms of chemical composition and their effect on rumen microbes or the host animal (D'Mello, 1992a). These nutritional differences could be attributed to age, concentration of antinutritional factors (secondary compounds) and form (fresh or dried) of presentation. These factors determine their chemical composition, palatability, intake, the extent and rate of degradation, digestibility and nutrient utilization by ruminants fed predominantly low quality roughages.

Many browse species have been documented as useful animal fodders. Listings of browses of potential value as animal fodders have been published by McKay and Fradsen (1969), Skerman (1977), Dicko (1980), Lamprey et al. (1980), Le Houérou (1980a, 1980b, 1980c), NAS (1980), Walker (1980), ILCA (1985b), Brewbaker (1986), Turnbull et al. (1986), Dicko and Sayers (1988), Keya et al. (1991) and Djogo (1992). A compendium of these lists is presented in Table 1, which includes over 75 genera. Many collections contain numerous accessions within a species. For example, ILCA (1985b) lists 25 accessions of *Aeschnomene americana* and 96 accessions of *Cajanus cajan* in their collection. Although not all browses are legumes, more than 200 species of leguminous trees are reported to be used for fodder, with most species tropical or sub-tropical in origin. The most commonly used species come from the genera *Acacia, Albizia, Calliandra, Desmanthus, Desmodium, Gliricidia, Leucaena, Prosopis and Sesbania* (Brewbaker, 1986). Although there is considerable diversity, past research and development activities have tended to work on a very narrow range of the available germplasm, in which *Leucaena leucocephala and Gliricidia sepium* in Asia and Africa and *Erythrina poeppigiana* in Latin America have been prominent. This is unfortunate as the narrower focus has tended to overlook many other valuable trees like *Acacia* species.

The importance of browse in the diet of herbivores is reflected in reports from Africa, Latin America and Australia. In northern Africa, browse forms 60-70% of rangeland production and 40% of the total availability of animal feeds in the region. The annual production is about 1.5 kg of dry matter ha^{-1} mm^{-1} of annual rainfall of which 50% is consumed (Le Houérou, 1980c). Browse is also a component of alley cropping (Atta-Krah, 1990). In India, browse is the principal feed for goats and meets over 60-70% of the forage requirements, of which the leguminous types of browse are especially important.

Based on maintenance requirements of cattle, sheep and goats (Devendra, 1995), browse (energy value of which varies from 2.95 to 5.31 MJ ME kg^{-1} DM) alone cannot ensure the maintenance requirements of cattle (6.02 MJ ME kg^{-1} DM).

Table 1. Tree and shrub fodders documented as being useful animal fodders

Source: Skerman (1977), ILCA (1985b) Brewbaker (1986), Turnbull et al. (1986), Djogo (1992).

Acacia acola
A. acuminata
A. adsurgens
A. albida
A. aneura
A. angustisima
A. arabica
A. aulacocarpa
A. baileyana
A. bidwillii
A. brachystachya
A. brevispica
A. burrowii
A. cambagei
A. cana
A. catechu
A. catenulata
A. chisholmi
A. coriacea
A. cunninghamii
A. cyclops
A. cyperophylla
A. dealbata
A. deanei
A. decora
A. decurrens
A. doratoxylon
A. estrophiolata
A. excelsa
A. fernesiana
A. floribunda
A. georginae
A. gerrardii
A. giraffae
A. hakeoides
A. harpophylla
A. holosericea
A. homalophylla
A. horrida
A. karoo
A. kempeana
A. koa
A. leptoclada
A. ligulata
A. linifolia
A. linophylla
A. litakunensis
A. macrothyrsa
A. melanoxylon
A. mellifera
A. microbotyra
A. myrtifolia
A. nigrescens
A. nilotica
A. nubica
A. oswaldii
A. pedula
A. penninervis
A. peuce
A. plectocarpa
A. podalyraefolia
A. polyacantha
A. pruinocrapa
A. pycnantha
A. retinodes
A. salicina
A. saligna
A. scerosperma
A. senegal
A. seyal
A. shirleyi
A. sieberiana
A. sophorae
A. sparsiflora
A. stenophylla
A. suavolens
A. subulata
A. sutherlandii
A. teprina
A. tenuissima
A. tetragonophyll
A. tortilis
A. trineura
A. tumida
A. verticillata
A. victoriae
Aescynomene abyssinica
A. americana
A. brasiliana
A. elaphroxylon
A. falcata
A. histrix
A. schimperi
A. sensitive
A. villosa
Albizia adianthifolia
A. africana
A. amara
A. basaltica
A. falcata
A. harveyi
A. julibrissin
A. lebbeck
A. lophantha
A. malacophylla
A. toona
A. zygia
Allocasuarina decaisneana
A. littoralis
Alphitonia excelsa
Antiaris africana
Atalaya hemiglauca
A. atacamensis
A. bunburyana
A. canescens
A. cinerea
A. confertifolia
Atriplex glauca
A. halimus
A. leucoclada
A. leneanis
A. nummularia
A. polycarpa
A. magodioides
A. semibaccata
A. undulata
A. vesicaria
Atylosia scarabaeoides
Azadirachta indica
Banksia integrifolia
Baphia nitida
Bauhinia purpurea
B. retusa
B. refescens
B. variegata
Brachchiton populneum
Brachistegia spiciformis
Buckinghamia celsissmia
Cajanus cajan
Calliandra calothyrsus
C. surinamensis
Callitris endicheri
Cassia artemisioides
C. brewsteri
C. chatelainiana
C. eromophila
C. nemophla
C. oligophulla
C. siamea
C. sturtii
Casuarina cristata
C. cunninghamiana
C. decaisneana
C. obesa
C. stricta
Celtis kraussiana
Ceratonia siliqua
Chamaecytisus palmensis
Codariocalyx gyroides
Colophospermum mopane
Combretum imberbe
Cordia africana
Crotolaria anagyroides
Cyamopsis tetragonoloba
Dalbegia sisoo
Daniella oliveri
Desmanthus barbatum
D. virgatus
Desmodium capitatum
D. cinereum
D. discolor
D. distortum
D. gyroides
D. lasiocarpum
D. tortuosum
Dicrostachys cinerea
Dodonaea viscosa
Dovyalis spp.
Enrharta calcycina
Entada abyssinica
E. africana
Eriosema psoraloides
Eremophila leucophylla
E. longifolia
E. maculata
Eriocephalus ericoides
E. umbellatus
Erythrina abussinica
E. brucei
E. burana
E. melanacantha
E. poeppigiana
Eucalyptus brevifolia
E. gamophylla
E. gongylocarpa
E. ochrophloia
Exomis microphylla
Felicia filifolia
F. murucata
Ficus thonningii
Flemingia macrophylla
Geijera parviflora
Gleditsia triacanthos
Gliricidia sepium
Guazuma ulmifolia
Hermannia trifurcata
Hirpicium integrifolium
Indigofera arrecta
Kigelia africana
Leucaena collinsii
L. diversifolia
L. leucocephala
L. pallida
L. pulverulenta
Lonchocarpus capassa
Lophira procera
Maireana brevifolia
M. polypterygia
Milletia thonningii
Monochlamys albicans
Moringa stenopetala
Napoleona vogeli
Newboldia laevis
Olea africana
Osteospermum pachypteris
O. scariosum
O. sinuatum
Parkia clappertoniana
parkinsonia aculeata
Peltophorum pterocarpum
Pentzia lanata
Piliostigma thinningii
Pithecolobium dulce
Pittosporum phylliraeoides
Pollichia campestris
Prosopis alba
P. chilensis
P. cinereria
P. glandulosa
P. juliflora
P. pallida
P. tamarugo
Pterocarpus erinaceus
P. marsupium
P. santalinoides
Ptilotus obovatus
Rhigozum obovatum
Ricinodendron headelotti
Robinia pseudoacacia
Samanea saman
Santalum spicatum
Sesbania aculeata
S. formosa
S. grandiflora
S. rostrata
S. sesban
Simmondisia chinensis
Spodias mombin
Tamarindus indica
Terminalia arostrata
Tetragonia hirsuta
Ventilago viminalis
Vernonia amygdalina
Zizyphus nummularia

It can, however, ensure the maintenance of sheep (5.17 MJ ME kg^{-1} DM), but does not allow production; while in goats, maintenance and production may be provided on a pure browse diet (4.72 MJ ME kg^{-1} DM). The data explain why only goats, camels and some wild herbivores can survive on depleted rangelands, where browse constitutes most of the feed. It also explains why goats and camels are less affected by catastrophic droughts in the Sahel of Africa, compared with sheep and cattle (Le Houérou, 1978).

Nutritive value of browses

The nutritive value of forages depends on the voluntary intake of the feed consumed, and the extent to which the quantity of dry matter eaten by the animal supplies dietary energy, proteins, minerals and vitamins. Much will depend therefore on the actual quantity of feed eaten by the animal on a daily basis. With browse legumes, the quantity eaten is likely to be relatively small, partly because of the sparsity of feeds, as well as the fact that the legumes are seldom eaten exclusively. The acceptance or edibility (palatability) of browses has been related to both physical characteristics (hairiness, bulk density) and the presence of compounds which may affect taste and appetite (volatile oils, soluble carbohydrates, antinutritional factors). Palatability is as important as digestibility in determining voluntary intake of roughages (Campling, 1966). Contrasting views on palatability and intake have been proposed. Greenhalgh and Reid (1971) and Weston and Davis (1986) proposed that low palatability could affect intake, while Gherardi et al. (1991) observed that rumen digesta load and apparent fractional rate of digestion were more associated with intake than palatability.

Bulkiness is an important determinant of intake (Aitchison et al., 1986). Tree leaves are bulky and their rate of degradation and passage out of the rumen may affect the extent of basal diet substitution rate. The chemostatic theory and metabolic satiety among others, have been observed to influence the intake of roughages when highly digestible and less bulky supplements such as grains and oilseed cakes are fed (Egan and Moir, 1965). Physical factors that determine roughage quality include the presence of cuticle waxes, hairs, lignin, crude protein and cellulose. The plant cell wall has been demonstrated to be the primary restrictive determinant of forage intake (Van Soest, 1994). The productivity of ruminants is closely associated with the capacity of a feed to promote effective microbial fermentation in the rumen and to supply the quantities and balances of nutrients required by the animal tissues for different productive states.

Milford and Minson (1968) have reported relationships between voluntary feed intake (VFI) and dry matter digestibility (DDM) for legumes with the corresponding regressions for *Chloris gayana, and Panicum* species.

Legumes VFI = 1.76DDM - 44.5 RSD $\pm$ 8.5 (r^2 = 0.86)

Chloris gayana	VFI = 0.74DDM + 3.4	RSD ± 3.7 (r^2 = 0.73)
Panicum species	VFI = 1.42DDM - 20.6	RSD ± 6.8 (r^2 = 0.76)

Minson (1988) concluded that tropical legumes appear to have a higher voluntary intake than *C. gayana,* but a similar intake to that reported for *Panicum* species. This point is also supported by the data of Devendra (1982) in comparative digestibility studies on the nutritive value of *L. leucocephala* and elephant grass *(Pennisetum purpureum)* fed to both goats and sheep. Smith and Van Houtert (1987) have reported that *in vivo* organic matter digestibility of *Albizia lebbek, G. sepium, L. leucocephala and Sesbania grandiflora* was comparable and in some cases higher than *P. maximum,* and supplied soluble carbohydrates and fermentable nitrogen for rumen and post-rumen digestion. Considerable variation exists in dry matter intakes between provenances, families within provenances and individual plants within the same family in some browse legumes such as *G. sepium,* and this is reflected in the range of data reported, from 30.2 to 63.3 g $kg^{-0.75}$ (Kass et al., 1992). Likewise Pezo et al. (1990) and Larbi et al. (1996) have reported considerable variations in nutritive value between and within species of the genus *Erythrina* in terms of crude protein content, protein solubility and *in vitro* dry matter digestibility. Browse, however, is seldom utilized exclusively. In most situations, its practical use is as a supplement to enhance the intake and utilization of other fibrous crop residues like cereal straws and hays, and thus meet the maintenance and variable levels of production requirements (Kaitho, 1992; Ooting, 1993).

There is no simple predictor of the quality of tree herbage. Chemical composition alone is an inadequate indicator of nutritive value since the availability of nutrients from forages is variable. Digestible dry matter (or energy) intake is also a poor predictor of potential productivity since the composition of nutrients absorbed is not described. Modern concepts of feed evaluation require that quality be assessed in terms of the capacity of a feed to supply nutrients in proportions balanced to meet particular productive functions (Leng, 1986). The nutritive value of feeds should therefore be ranked on the following characteristics:

- Voluntary consumption potential
- Potential digestibility.
- High rates of microbial protein synthesis in the rumen relative to volatile fatty acids produced (protein/energy (P/E) ratio).
- Ability to provide by-pass nutrients (protein, starch, lipid) for absorption in the small intestine.

The protein:energy ratio is an important factor that is associated with the efficiency of feed utilization. Since anaerobic fermentative digestion in the rumen provides microbial cells which supply the protein to the animal, the efficiency of microbial growth therefore influences the P/E ratio. Poor microbial growth due to inadequate dietary N, for

example, will result in a low P/E ratio and, conversely, adequate supplementation and good rumen function enable a good P/E in the nutrients available to the animal (Leng, 1982).

It has recently been shown that the presence of rumen protozoa reduces the P/E ratio in the nutrients absorbed (Bird, 1991). In this context, it has been demonstrated that a number of tropical browse legumes have anti-protozoal properties when used between 10-100 g kg^{-1} in the diet (Leng et al., 1992). These include several *Acacia* species, *L. leucocephala*, *Vigna parteri*, *Cassia rotundifolia*, *Enterolobium cyclocarpum* and *E. timboura*. Practical trials using anti-protozoal forages have increased productivity in animals due to a greater supply of essential amino acids, and where the basal forage is high in protein, extra dietary protein becomes available for post-ruminal digestion.

Similar to grasses, the crude protein content of tropical browse legumes decreases with maturity. Digestibility data for tropical browse legumes are not as extensive as for the pasture legumes. The digestible crude protein (DCP) values vary considerably, and are associated especially with the level of crude protein content and the species of animals used. Low crude protein digestibilities have been associated with low digestibility. Minson (1988) has calculated a prediction equation that relates DCP per 100 units of feed to the crude protein (CP) percentage of the dry matter *as follows:*

Legumes	DCP = 0.93CP - 3.99	(RSD $\pm$ 1.17, r^2 = 0.96)
Grasses	DCP = 0.90CP - 3.25	(RSD $\pm$ 0.84, r^2 = 0.98)

The equation for legumes is similar to the one for grasses (Milford and Minson, 1968), suggesting that the digestive efficiency of protein in both these two types of feeds is comparable for similar CP contents.

The use of crude protein or digestible crude protein as protein requirement indicators are currently regarded as inadequate and unsatisfactory (AFRC, 1992). This is because they fail to recognize the close relationship between nitrogen requirements and either total energy intake or density of the ration fed. Nitrogen source and role of rumen microbes in its metabolism to amino acids is not considered. The new systems of feed evaluation systems (ARC, 1984; AFRC, 1992; DVE/OEB (Tamminga et al., 1994)) recognizes that dietary protein should be expressed in terms of rumen degradable protein and undegradable dietary protein.

The degradability of dietary protein plays a central role in feed evaluation. The extent and rate of degradation determines not only the contribution which dietary protein makes to the rumen microbial need, but also the amount of protein which passes through the rumen undegraded and which subsequently becomes available for digestion by the host animal. Diets high in rumen degradable protein tend to be higher in fractional outflow rates of the solid and liquid phases (Newbold et al., 1987). The importance of undegradable protein lies in the fact that the ratio of protein to

energy supplied by the rumen micro-organisms is fixed, whereas the ratio of protein to energy required by the host animal increases with increased level of production such as growth and lactation (Webster, 1984).

Different nitrogen sources were found to elicit different responses, with protein supplements being more effective than non-protein nitrogen (McAllan and Smith, 1983). Goodchild (1990) obtained significant responses in total dry matter and stover intakes when urea was fed with graded levels of *Leucaena*. Increased dietary nitrogen resulted in increased numbers of rumen bacteria, with considerably greater increase with protein N than with urea-supplemented diets (Maeng and Baldwin, 1976; Teather et al., 1980).

The digestibility of plant material in the rumen is related to the proportion and extent of lignification of plant cell walls (NDF). Browse leaves with a low NDF content (20-35%) are usually of high digestibility and species with high lignin contents are often of low digestibility. The dry matter digestibility, which is related to nutrient composition varies widely among browse species. A range from 38 to 78% was given by Skarpe and Bergstrom (1986) working in Botswana with Kalahari woody species. Similar findings had been reported by McKay and Fradsen (1969) and Walker (1980). However, digestibility alone gives a poor assessment of the nutritive value of browses and shrubs. This is because, often the relationship between digestibility and intake are inconsistent. Low intake and digestibility of browse may have some connection with the deleterious substances that it may contain.

A number of authors have attributed low digestibility of a wide range of forage legumes to high concentration of condensed tannins (Barry and Duncan, 1984; Barry and Manley, 1984; Kaitho et al., 1993). Bamualin et al. (1980) showed that the lignin content of browses was negatively correlated (-0.924) with feed digestibility in nylon bags. However, Ahn et al. (1989) demonstrated a poor relationship between tannin content and rumen digestibility using a wide range of browses, while, Kumar (1983) indicated that the condensed tannin content was negatively correlated to crude protein apparent digestibility. Robbins et al. (1987) showed that the digestible protein in plants containing significant amounts of tannins was low and that the reduction was proportional to the protein precipitating capacity of tannins.

Chemical composition

The chemical composition of browses has been reported variously, but not exhaustively, by several individuals. These include *inter alia* data for Africa (Rose-Innes and Mabey, 1964; Le Houérou, 1980b), Asia and the Pacific (Devendra, 1992), the developing countries (NRC, 1981; Kearl, 1982) and information on the use of the forage legumes, including browse, of relevance to the tropics (Skerman et al., 1988).

Much of the considerable information now available on the chemical composition of browses is from proximate analysis and is of limited value as a predictor of nutritive value (Topps, 1992). Analyses based on detergent extraction are more useful since plant dry matter is separated into a completely digestible fraction (Neutral detergent solubles representing cell contents, and a partially digestible fraction (Neutral detergent fibre) representing plant cell walls. Degradability coefficients, particularly the potentially degradable fraction may be equally useful. The high variability in the nutrient content of browses often encountered in literature could be attributed to within species variability due to factors such as plant age, plant part, harvesting regimen, season and location.

Table 2 shows the chemical composition of a selected range of browse species. The crude protein content (12-30%) is usually high compared with mature grasses (3-10%). Protein is digested in the rumen to provide ammonia and amino acids or peptides for microbial protein synthesis.

Microbial cells then pass to the small intestine, providing a major source of absorbed amino acids for the ruminant. In some cases, feed proteins may escape degradation (by-pass proteins) in the rumen and provide additional protein for absorption in the small intestine. The concentration of ammonia nitrogen associated with maximum microbial output or fermentation varies from 70 to 760 mg l^{-1} (Hume et al., 1970; Allen and Miller, 1976; Mehrez et al., 1977; Oosting, 1993), lower values are associated with decreased microbial activity (digestion) and are indicative of nitrogen deficiency (Norton et al., 1992). Feeds containing less than 6% crude protein (Hoover, 1986) are considered deficient as they cannot provide the minimum ammonia levels required. Most of the browses have higher nitrogen than this value, and may be judged adequate in protein. However, tannins found in most browses form complexes with plant proteins which decreases their rate of degradation in the rumen, thereby decreasing rumen ammonia concentrations and increasing the amount of plant protein by-passing the rumen. Where the tannin-protein complexes are dissociated in the low pH of the abomasum, an additional source of protein is available for absorption by the animal. In other cases, the tannins protect the proteins from digestion even in the small intestine (Norton et al., 1992).

Mineral content of browses

There is less data available in the literature on the mineral concentrations in browses, particularly the local species (Skerman et al., 1988). Table 3, shows some values for the mineral concentrations in a range of browses. There is little information available on the trace elements (Cu, Mn, Zn, Co, I) and only fragmentary data on the macro-elements. Sulphur (S) in plant material is mainly found in the form of S-containing

Table 2. The chemical composition (g kg^{-1} DM) of a selected range of browse species.

Species	CP	Ash	NDF	ADF	Lignin	Tannin	Reference
Acacia albida	143	27	374	279	45		Tanner et al., 1990
Acacia aneura	110	35	511	396	206	70	Goodchild, 1990
	114	48	498		194		Leche et al., 1982
Acacia anguistisima	225	46				66	Ahn et al., 1989
Acacia mangium	120		619	610	422		Blair et al., 1988
Acacia nilotica	130	49	316	225	53		Tanner et al., 1990
Acacia saligna	128		573	429	207		Nsahlai et al., 1995
Acacia siberiana	127	52	370	282	58		Tanner et al., 1990
	212		412	340	160		Nsahlai et al., 1995
Acacia seyal	206		228	172	69		Reed et al., 1990
Acacia tortilis	136	47	324	242	48		Tanner et al., 1990
Albizia chinensis	263	46	603	348	145	33	Robertson, 1988
	151	53					Gohl, 1981
	211	145	354	246		23	Ash, 1990
Albizia lebbeck	222	46	377				Le Houérou, 1980b
	181	80	265				Gohl, 1981
Cajanus cajan	158	55	314	292	100		Bamualin et al., 1980
	201		539	371	175		Nsahlai et al., 1995
Calliandra calothyrsus	212	43	259	209	69	111	Robertson, 1988
	173	40	302	229	84	96	Ahn, 1990
Casia siamea	188	52	535				Akkasaeng et al., 1989
Chamaecytisus palmensis	178		342	235	64		Nsahlai et al., 1995
	184		341	204	69	56	Bonsi, 1995
Desmanthus virgatus	146	85	256	195	91		Bamualin et al., 1980
Enterolobium cyclocarpum	168		361	296	141		Blair et al., 1988
Erythrina bentipoene	155		495	393	65		Nsahlai et al., 1995
Erythrina variegata	175		532	425	68		Nsahlai et al., 1995
	264	91	457	343	9		Rajaguru, 1990
Gliricidia sepium	150	55	272	212	55		Bamualin et al., 1980
	183	59	656	357		20	Ash, 1990
	275	60	255	216	94	30	Robertson, 1988
Leucaena diversifolia	308	75	246	114	41		Siaw et al., 1993
Leucaena leucocephala	188		453	190	79		Nsahlai et al., 1995
	294	83	216	104	32		Siaw et al., 1993
	258	69	309	234	87	55	Goodchild, 1990
	267	57	312	226	99	37	Robertson, 1988
	269		383	226	68		Van Eys et al., 1986
Leucaena pallida	206		420	245	105		Nsahlai et al., 1995
	326	73	211	113	38		Siaw et al., 1993
Leucaena pulverulenta	277	87	192	107	37		Siaw et al., 1993
Leucaena revoluta	324	68	242	141	52		Siaw et al., 1993
	269		405	234	93		Nsahlai et al., 1995
Samanea saman	221	60					Gohl, 1981
	240	46					Brewbaker, 1986
Sesbania sesban	356	94	203	108	24		Siaw et al., 1993
	241		206	141	25	13	Bonsi, 1995
	213	80	219	153	36	ND	Robertson, 1988
Vernonia amygdalina	148		312	277	61	47	Bonsi, 1995

CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre; ND: not detected

Table 3. The concentration of minerals (g kg^{-1} DM) in leaves of some browse species.

Species	N	S	P	N:P	K	Ca	Ca:P	Reference
Acacia aneura	24.9	1.2	1.3	20.8				Ahn et al., 1989
	11.0		0.4	27.5	7.9	26.0	65.0	Le Houérou, 1980a
	20.0	1.4	0.8	25.0		10.6	13.3	Entwistle & Baird, 1976
Acacia anguistisima	36.0	1.4	1.3	27.7				Ahn et al., 1989
Acacia albida	23.5		1.8	13.1	12.5	9.2	5.11	Le Houérou, 1980a
	31.5		2.3	13.7		10.0	4.3	Gohl, 1981
Albizia chinensis	42.2	1.8	2.0	21.1				Ahn et al., 1989
	42.1	1.8	1.9	22.2				Robertson, 1988
	24.2		1.4	17.3		11.7	8.4	Gohl, 1981
Albizia lebbeck	38.5	2.0	1.6	24.1				Ahn et al., 1989
	46.7		2.0	23.4		18.0	9.0	Brewbaker, 1986
Calliandra calothyrsus	36.8	1.9	1.5	24.5				Ahn et al., 1989
	33.9	2.0	1.4	24.2				Robertson, 1988
Cajanus cajan	25.3		2.2	11.5				Bamualin et al., 1980
	34.2		2.4	14.3		8.9	3.7	Gohl, 1981
Chamaecytisus palmensis	34.0		1.4	24.3	5.3	4.5	3.2	Borens & Poppi, 1990
	36.0		1.7	21.2	7.2	4.8	2.8	Borens & Poppi, 1990
	29.5	1.5	1.2	24.6	5.9	10.5	8.8	Bonsi, 1995
Codariocalyx gyroides	31.6	1.2	1.4	22.6				Ahn et al., 1989
Desmanthus virgatus	23.4		1.9	12.3				Bamualin et al., 1980
Enterolobium cyclocarpum	40.0	2.7	1.7	23.5				Ahn et al., 1989
	26.9		1.4	19.2		6.7	4.8	Gohl, 1981
Gliricidia sepium	44.2		1.9	23.3	27.5	11.9	6.3	Chadhokar, 1982
	37.3		1.8	20.7	30.0	13.8	1.7	Chadhokar, 1982
	41.8		2.8	14.9	33.1	10.5	3.8	Carew, 1983
Leucaena leucocephala	42.0	2.2	1.6	26.3				Ahn et al., 1989
	42.8	2.6	1.9	22.5				Robertson, 1988
	32.5		1.6	20.3	13.0	23.0	14.4	Brewbaker, 1986
	44.5		2.9	15.3		5.4	1.9	Gohl, 1981
	40.6	2.3	1.8	22.6	11.4	20.0	11.1	Bonsi, 1995
Samanea saman	44.7	2.8	1.5	29.8				Ahn et al., 1989
	35.4		2.1	16.8		14.2	6.8	Gohl, 1981
Sesbania grandiflora	55.7		3.3	16.9		23.3	7.1	Brewbaker, 1986
	41.5		4.7	8.8		13.2	2.8	Gohl, 1981
Sesbania sesban	42.2	2.7	2.4	15.6				Ahn et al., 1989
	16.0		2.8	5.7	18.4	22.1	7.9	Lamprey et al., 1980
	42.4		4.3	9.9	27.8			Gohl, 1981
	38.5	2.1	2.7	14.3	14.6	17.4	6.4	Bonsi, 1995
Vernonia amygdalina	23.7	2.2	0.7	33.9	21.1	11.7	16.7	Bonsi, 1995

N: nitrogen; S: sulphur; P: phosphorus; K: potassium; Ca: calcium

amino acids and is required, together with N and phosphorus (P), for microbial protein synthesis in the rumen. Concentrations greater than 1.5 g kg^{-1} DM or N:S ratios less than 15:1 are considered adequate (Norton, 1994).

The minimum requirement of ruminants for P varies from 1.2-2.4 g P kg^{-1} feed dry

matter depending on physiological function and the level of production. Browses generally have high P concentrations. Mulga *(Acacia aneura)* is an exception with low P content and responses of sheep to P (+ molasses) supplementation have been claimed (McMeniman and Little, 1974). Calcium (Ca) is closely associated with P metabolism and a Ca:P ratio of 2:1 is usually recommended for ruminant diets. Ca is rarely limiting in forage diets and the same is true for tree forages (Table 3). However, high concentrations of oxalic acid in leaves may decrease the availability Ca during digestion. Gartner and Hurwood (1976) have suggested that high oxalate levels in Mulga affect Ca metabolism in sheep. Magnesium and potassium (K) are also found in excess of requirements in tree leaves and are seldom a limiting dietary factor in ruminants.

Although sodium (Na) deficiency has been recorded in cattle grazing tropical pastures, short term deficiencies are rare. Ruminants effectively conserve tissue Na (saliva) by recycling it through the rumen (Norton, 1994). The recommended requirement for Na in ruminant diets is 0.7 g kg^{-1} DM. Some tree species appear to be marginal in Na, but deficiencies are probably not common as browse leaves usually form only part of a ruminant's diet. Deficiencies of minerals other than S and P appear to be unlikely.

Voluntary intake and digestibility of browses

In vitro digestion techniques (Tilley and Terry, 1963; McLeod and Minson, 1978) provide comparative estimates of dry matter digestibility among feeds. These values may be used to rank the quality of feeds but usually under estimate values obtained from *in vivo* digestibility. New techniques which measure the rates of feed digestion in nylon bags suspended in the rumen *(in sacco)* (Mehrez and Ørskov, 1977; Ffoulkes, 1986) can also be used to rank feeds. This technique has the advantage that the rates of digestion of different feed components (protein, fibre) may also be calculated. *In sacco* digestibility (24-48 h degradability) usually overestimates *in vivo* digestibility, however, if the rate of passage is taken into account the reverse is often true. Table 4 shows values for *in vitro, in sacco and in vivo* digestibility estimates of a few selected browses and intake of the leaves by different ruminant species. *In vitro* (IVD) and *in sacco* (ISD) estimates of feed digestibility generally rank feeds in the same order, but these values are not accurate predictors of either *in vivo* digestibility (DMD) or voluntary feed intake (VFI). For this reason, these techniques provide only qualitative data on feed nutritive value. The value of IVD and ISD, as estimates of quality, is to predict DMD, which is closely related to VFI for tropical grasses (Minson, 1982).

Data on Table 4 suggest that the same predictions cannot be made for browses. For example, similar values (66%) were found for the IVD of *tagasaste (Chamaecytisus*

Table 4. Some *in vitro*, *in sacco* and *in vivo* dry matter (DM) and nitrogen (N) digestibility and voluntary feed intakes values for ruminants given browse.

Species	digestibility (%)					Voluntary intake ($g\ kg^{-1}$ LW)	Animal species	Reference
	In vitro DM	*In sacco* DM	*In sacco* N	*In vivo* DM	*In vivo* N			
Acacia aneura	31.9			39.2		14.2	sheep	1
Acacia angustissima		55.0	39.0				goat	2
Albizia chinensis		37.1	26.4				goat	2
				37.6	32.3		sheep	3
Albizia lebbeck	54.5						goat	4
		63.4	78.2	57.3		17.7	goat	2
				64.4	82.2	23.2	sheep	5
				46.3	64.5		cattle	3
Cajanus cajan		53.0					cattle	6
				64.8	69.0		cattle	3
				50.9	60.0		sheep	3
				47.3	61.8	25.7	goat	7
				50.9	61.8	21.7	sheep	7
				54.6	68.8	25.1	cattle	7
Calliandra calothyrsus	48.0							4
	35.0							8
		52.7	35.9				goat	2
						16.6	sheep	10
		59.0					cattle	11
						25.9	sheep	11
Chamaecystisus palmensis	66.0			76.0	82.0	35.0	sheep	9
Codariocalyx gyroides		66.0	64.7				goat	2
Desmanhus virgatus		53.3					cattle	6
				47.7	44.0		cattle	3
Enterolobium cyclocarpum		87.6	95.8				goat	2
Gliricidia sepium		79.1	84.1				goat	2
		68.2					cattle	6
	66.0					34.6	goat	12
				54.8		25.8	sheep	10
				56.3	84.6	32.6	goat	13
Leucaena leucocephala		82.1	83.3				goat	2
				68.0		35.6	goat	14
				63.2		31.9	sheep	14
				54.8	65.0		cattle	3
Samanea saman		69.3	90.1				goat	2
Sesbania grandiflora	66.9							4
				62.7	74.0		sheep	3
Sesbania sesban	67.8							4
		90.6	96.0				goat	2

References

1: McDonald and Ternouth, 1979; 2: Ahn et al., 1989; 3: Gohl, 1981; 4: Topark-Ngarm and Gutteridge, 1986; 5: Lowry, 1989; 6: Bamualin et al., 1980; 7: Whiteman and Norton, 1980; 8: Baggio and Heuveldop, 1984; 9: Borens and Poppi, 1990; 10: Mahyuddin, 1983; 11: Palmer and Schlink, 1992; 12: Carew, 1983; 13: Murugan et al., 1985; 14: Yates, 1982.

palmensis) and *Gliricidia,* whereas *in vivo* digestibilities were found to be 76 and 55% respectively. Intake values were similar. Similarly, DMD was not a guide to intake of *Albizia lebbeck,* where sheep consumed significantly more fallen leaf (DMD 43%) than fresh leaves (DMD 64%). Conversely, goats appeared to consume similar amounts of *Leucaena* (35.6 g kg^{-1} LW) and *Gliricidia* (32.6 g kg^{-1} LW) despite large differences in digestibility (68.0 and 56.3%, respectively). These results suggest that factors other than the rate of digestion in the rumen determine the voluntary intake of browse herbage by ruminants. Kamalzadeh (1996) showed that rumen dry matter pool may also vary considerably. Low intakes associated with high feed digestibilities maybe related to the presence of compounds which are appetite depressants (Ahn et al., 1989). High feed intakes and low feed digestibilities may be related to rapid rates of passage of feed through the rumen such as might be found when the small leaflets of pinnate leaves are being consumed. Since there are no known techniques which reliably predict palatability and intake, the nutritive value index (VFI x DMD) of browse species can only be accurately determined by feeding trials. Feeding trials (long time studies) have the added advantage of also providing information on animal health and productivity (live-weight gain). The screening of browses for nutritive value by qualitative methods may therefore, lead to some erroneous conclusions if not supported by feeding trials. Tree legumes of low digestibility and high palatability would be rejected. The form in which the leaves are fed (fresh, wilted, dry) is also known to affect both intake and digestibility in some species (Palmer and Schlink, 1992; Bonsi, 1995).

Plant foliages and pods are normally fed dried or fresh, however, pre-feeding handling could change the chemical composition and nutritive potential (Burns, 1985; Mahyuddin et al., 1988). The extent of change may depend on the source, age, botanical fraction and degree of drying. Ahn et al. (1989) found that drying at 60°C for 24 h resulted in lower phenolic and condensed tannins but the extent of depression varied among species. Freeze drying resulted in a higher dry matter degradability at 48 h compared to oven drying. Mahyuddin et al. (1988) observed no significant ($P>0.05$) differences between all forms of drying (sun, oven, and freeze) in terms of 48 h dry matter disappearance using the nylon bag technique for *Gliricidia* and *Leucaena*. However, the nylon bag 48 h figures from all drying treatments were significantly lower than those obtained from fresh material of *Calliandra*, *Centro*, cassava and other feeds tested. Perera et al. (1992) observed no significant difference between fresh and dried materials (*Samanea saman, Gliricidia sepium, Albizia fulcataria, Tithonia diversifolia, Erythrina variegata, Leucaena leucocephala*) in terms of rumen degradable and intestine digestible protein. Bamualin et al. (1984) observed that fresh *Leucaena* gave a less intensive substitution compared to dry foliage and that drying increased the by-pass nature of protein compared to their fresh counterparts.

However, Bonsi (1995) observed that fresh *Leucaena* substituted the basal roughage to a greater extent than dry *Leucaena*, despite the fresh form having a higher dry matter disappearance. The bulky nature of the fresh foliage was suggested as the limiting factor. In another trial, Bonsi (1995) compared *Leucaena* and *Sesbania* and came to the conclusion that substitution rate are lower for forage supplements that disappear relatively faster from the rumen. In a similar trial, Umunna et al. (1995) demonstrated lower substitution rate for *Sesbania* than for *Chamaecytisus palmensis*.

While most browse species contain high concentrations of protein, degradability of protein, as estimated by *in sacco* method, varied considerably. High degradability (> 78%) was found in all species which did not contain tannins, whereas most tannin-containing species had low degradability (<39%). Exceptions were *Codariocalyx, Gliricidia and Leucaena* which showed high degradability (64-84%) yet contained 3-7% tannins. The high intakes of the latter two species suggest that tannins, in these examples, did not reduce palatability. There is little known about the nature and chemistry of tannins in browses. It seems that not all tannins decrease protein degradability in the rumen. Ahn et al. (1989) have shown that the drying of tree legume leaves decreases tannin content, and in the case of *Gliricidia* and *Tipuana tipu*, removes all tannin. The decreased tannin content after drying was associated with a decreased *in sacco N* digestibility for *T. tipu* but there was no significant effect on the degradability of *Gliricidia*. In all other species, drying decreased tannin content and increased N degradability. Drying therefore, may be a practical means of manipulating protein availability from browses.

Limitations to nutritive value of browses as sole feed

Most browses contain anti-nutritive factors (phenolics, saponins, fluoroacetates, amino acid derivatives) which adversely affect nutritive value. For this reason, depending on the species, browses as sole feed may be of lower nutritive value than as a supplement to other feeds. The significance of secondary plant compounds become more evident when browse herbage is the only feed consumed.

Acacia species are generally of low nutritive value and as sole feed they hardly meet the maintenance requirements of livestock. Mulga *(Acacia aneura)* has received considerable research attention in Australia. Its nutritive value may be greatly increased by the provision of specific supplements. McMeniman and Little (1974) first demonstrated that supplementation of mulga with phosphorus in molasses increased wool growth in sheep. McMeniman (1976) also showed that sheep on Mulga responded to the addition of urea to their diet even though the diet contained more than the minimum level of crude protein. Pritchard et al. (1988) showed that the feeding of polyethylene glycol (PEG) to sheep fed mulga markedly increased feed

intake, weight gain and wool growth. The low quality of mulga is therefore related to its content of condensed tannins and their capacity to bind feed proteins. These proteins are poorly digested in the rumen and appear also to be indigestible in the intestines. Consequently, sheep consuming mulga have low rumen ammonia and sulphur levels, which can be corrected by urea or sulphur supplementation. The addition of PEG preferentially binds the tannins thereby making plant proteins available for digestion. The increased digestion rate stimulated feed intake and changed mulga from a maintenance ration to one on which sheep grew.

Browses as feed supplements

(a) Live weight gains

The aim of supplementation is to use judicious amounts of another feed or feed additives to optimize the utilization of the least expensive basal material and increase productivity. Among other factors, feed supplements should be palatable, maximize the outflow of microbial protein from the rumen, provide by-pass protein to augment the supply of amino acids from microbial protein to meet the protein requirements of the animal, increase energy intake and increase efficiency of absorption of nutrients from he rumen and intestines. It should also enhance the intake of the basal diet or at least maintain its intake. An ideal forage supplement should increase or at least maintain intake of the fibrous basal diet rather than substitute for it (McMeniman et al., 1988).

Rapidly degrading leaves may release ammonia nitrogen in the rumen. This may not be efficiently utilized due to the slow rate of roughage degradation. Protein and energy should be available at the same time for utilization by rumen microbes when supplements are fed with roughages. Synchronizing the release of energy with ammonia or adoption of different supply patterns to achieve synchrony may be essential under such circumstance. However, responses to energy-protein supply patterns have been confounding. While Salter et al. (1983) did not observe any significant effect of energy-protein synchronization on efficiency of N^{15} capture by rumen microbes, Rooke et al. (1987) obtained increased microbial growth efficiency and ascribed this to synchronization.

There is extensive and diverse literature on the effects of leguminous browse supplementation on the productivity of cattle, sheep and goats. Browse leaves, particularly *Leucaena* and *Gliricidia*, have been used as supplements to a wide range of forages and agricultural by-products. Tagasaste (*Chamaecytisus palmensis*) has recently been shown to be a potentially useful leguminous shrub on sandy soils in the cooler low rainfall environments of Western Australia (Oldham, 1992). However,

Varvikko et al. (1992) observed that poor palatability may be a major problem in feeding tagasaste to growing cattle. Table 5 provides information on the response of cattle, sheep and goats to supplements of browse leaves to low quality hay diets. The levels of supplementation ranged from 15 to 35% of dry matter. Although weight

Table 5. The effects of supplementation with browse legume leaves on the intake of low quality forages and productivity of cattle, sheep and goats.

Browse	Animal	Basal diet	Voluntary intake ($g\ kg^{-1}$)		Dietary DMD%	LW gain ($g\ d^{-1}$)	Reference
			Tree leaves	Basal diet			
Leucaena leucocephala	Goat	Maize stover	-	10.3	46.0		Banda & Ayoade 1986
			5.5D	10.3	51.0		
	Sheep	Sorghum stover	-	24.6	41.7	-44	Goodchild 1990
			5.9D	32.8	46.7	85	
	Cattle	Natural grass	-	20.2	42.0	-20	Wahyuni et al., 1982
			5.2D	26.1	44.0	290	
	Cattle	Rice straw		-	18.3	37.6	Moran et al., 1983
			6.8D	15.9	40.3		
Gliricidia sepium	Goat	-	32.6F	-	56.3	60-75	Murugan et al., 1985
	Sheep	-	33.9F	-	-	39	
	Cattle	Rice straw	-	27.0	47.0	-113	Doyle et al., 1986
			11.0D	22.0	55.0	10	
Calliandra calothyrsus	Sheep	Barley straw	6.8F	14.5	36.3		Ahn 1990
			6.8D	22.9	59.		

D= dried, F= fresh; DMD: dry matter digestibility

changes were not measured in a number of these experiments, the increase in digestible dry matter intake may be predictive of improved weight gain. *Leucaena* supplements at a rate of 16% of DM were effective in converting a weight loss to a significant weight gain in both sheep and cattle. Higher levels (33% of DM) of *Gliricidia* were needed to convert a substantial weight loss in cattle to maintenance. Devendra (1988) recommended that, when used as supplements, the optimum dietary level of browses and shrubs should be about 30 to 50% of the ration on dry matter basis or 0.9 to 1.5 kg/100 kg body weight. The form in which the browse is fed appears to be an important determinant of the response obtained. The effects of drying of browses on response to supplementation is clearly shown in the studies of Robertson (1988). Dried browse promoted higher weight gains than fresh browse for all species, with no species superior. It is possible that drying may have two independent effects. It may increase the amount of protein by-passing the rumen as well as decrease the content of anti-nutritional factors.

Ahn (1990) found significant increases in intake and digestibility of barley straw fed to sheep when dried *Gliricidia* and *Calliandra* were offered as supplements. Nitis (1984) reported a case where sheep and goats fed on *Pennisetum purpureum* supplemented with 0.3 to 1.8 kg *Gliricidia* per day gained 17-27% more weight than the un-supplemented animals. With Bali cattle fed on 80% of natural grasses plus 9% Musa, and 11% of tree leaves (*Leucaena*), the increase in weight was 58% more than that of the control group. ILCA studies in Nigeria established that the use of *Leucaena* and *Gliricidia* as supplementary feeds significantly increased the growth and survival rates of lamb. Statistical analysis of the data showed that each 100 g of browse DM consumed per day raised the yearly productivity index by 1.41 kg lamb weaned/dam (ILCA, 1989).

Substitution effects have been observed with certain tree leaves and forage supplements (Moran et al., 1983; Mosi and Butterworth, 1985; Sarwatt, 1990; Bonsi 1995) but not in others McMeniman et al., 1988; Ash 1990). The extent of substitution depends on the type of roughage, bulk density of supplement (Bonsi 1995) and level of supplementation (Khalili, 1993). Goodchild (1990) found a negative substitution rate when he fed *Leucaena leucocephala* and maize stover. However, Van Eys et al. (1986) observed no substitution when animals were fed napier grass and supplemented with *Gliricidia, Leucaena* and *Sesbania*.

Under grazing situations, *Leucaena leucocephala* is the most studied. It has numerous advantages over all the other browses. Therefore it is not surprising that many studies have been carried out on the effect of feeding *Leucaena*, in pens or in situ, to a wide range of animals including cattle, sheep, goats, buffalo, pigs, deer, rabbits and poultry. Table 6 summarizes the results of a number of grazing experiments. The increase in live weight gain varied as access to *Leucaena* varied. This was expected in view of the differences in quantity and quality of the base pasture and the amount of *Leucaena* on offer.

The general conclusion from these studies is that supplementary grazing of *Leucaena* can substantially improve live weight gain over that from pure grass pasture. The increase will be greatest when the base pasture is low in quality and when intake of *Leucaena* is high. In situations where there have been no clinical signs of mimosine toxicity, animal production from *Leucaena*/grass pasture was appreciably higher than from pastures of the same grass species. Even higher daily live weight gains have been reported for shorter periods, e.g. 0.8 kg per head over 115 days (Cardoso, 1986), 0.9 over 200 days (Jones, 1979), 0.9 over 168 days (Clem et al., 1993), 0.7-1.3 over 57-146 days (Rakuita et al., 1992) and 1.1 over 90 days (Wildin, 1986).

Table 6. Live weight gains of cattle grazing either grass pastures with or without access to *Leucaena*.

Grass species	LWG (kg d^{-1}) -L	+L	Details of access to *Leucaena*	Reference
Native pasture	0.59	0.70	25% L (area basis)	Quirk et al., 1988
Native pasture	0.22	0.39	4 hours/day	Gandara et al., 1986
Native pasture	0.18	0.33	25% L (area basis)	Foster & Blight, 1983
Native pasture	-0.15	0.16	25% L (area basis)	Addison et al., 1984
Native pasture	0.23	0.51	6% L (area basis)	Zoby et al., 1989
Native pasture	0.25	0.35	25% L (area basis)	Quirk et al., 1990
Native pasture	0.25	0.56	100% L (area basis)	Quirk et al., 1990
Cenhrus ciliaris	0.60	0.60	10-20 hours/week	Carvalho et al., 1984
Brachiaria decumbens	0.49	0.64	4 hours/day	Paterson et al., 1982
Hyparrhenia rufa	0.27	0.35	10% L (area basis)	Paterson et al., 1983
Cynodon plectostachyus	0.29	0.41	4 hours/day	Palomo et al., 1980
Dicanthium caricosum	0.21	0.50	20% L (area basis)	Patridge & Ranacou, 1974
Pennisetum clandestinum	0.07	0.34	3 hours/day	Zacharias et al., 1991
Panicum maximum	0.52	0.67	30% L (area basis)	Castillo et al., 1989
Panicum maximum	0.52	0.67	30% L (area basis)	Castillo et al., 1989

L: *Leucaena leucocephala*

Experiments investigating the effects of increasing levels of supplementation of *Leucaena, Gliricidia, Sesbania* and *Albizia* for cattle, sheep and goats are summarised in Table 7. Two supplementation strategies are indicated viz., levels to prevent weight loss and levels which maximise live weight gains. The first strategy provides a conservative use of browse and the second a production oriented approach. The level of supplement required will depend on the quality of the basal feed. High levels of browse supplementation (33% of DM) of rice straw are required just to maintain cattle (Doyle et al., 1986; Moran et al., 1983). Where basal diet quality is higher, lower levels (15% DM) are probably sufficient for weight maintenance.

(b) Milk production

The results of experiments, primarily from Latin America, in which *Leucaena* was fed to dairy cows are summarized in Table 8. The increase in milk yield obtained after supplementing animals with *Leucaena* varied from 2 to 33%. In Malaysia Hassan et al. (1989) measured a higher milk production from grazed *Brachiaria decumbens-Leucaena* pastures (6.1 kg of milk per day) than from cows on "cut-and-carry" feeding of the same mixture (4.8 kg d^{-1}). Milk production from the grazed *Brachiaria-Leucaena* pastures was also higher than from grazed *Setaria sphacelata* fertilized with 300 kg ha^{-1} of N (4.9 kg d^{-1}).

Milera and Santana (1989) mentioned other advantages of *Leucaena viz.*, cows fed *Leucaena* ate less concentrate and pasture fertilizer requirements were reduced. Saucedo et al. (1980) also recorded higher live weight gains from cows and calves grazing a grass pasture supplemented with *Leucaena*. Stobbs (1972) measured 6290 kg of milk and 272 kg of fat per hectare from Jersey cows grazing a *Leucaena*-green panic (*Panicum maximum* var. trichoglume) pasture. Plucknet (1970) reported that Friesian cows grazing *Leucaena*-Guinea grass pastures` with some supplement produced 9780 kg milk/ha.

In the Kenyan costal lowland, Muinga et al. (1992) observed an increase in dry matter intake and milk yield and a reduced live weight loss in early lactation when Ayrshire/Brown Swiss X Sahiwal cows were fed graded levels of *Leucaena* (Table 9). Khalili and Varvikko (1992) substituted concentrate with *Sesbania sesban* and observed linear decreases in total DM intake and milk yield. Earlier, *Sesbania sesban* had been shown, in terms of milk yield and live weight change, to be as effective a supplement as cotton seed cake, when fed to lactating crossbred cows given a napier grass basal diet (ILCA, 1989).

Beneficial effects were observed by Tobon (1988) when milking cows grazing African star grass (*Cynodon nlemfuensis*) and receiving a constant level of energy (1 kg molasses/day) were supplemented with increasing levels of *Erythrina poeppigiana* foliage. Taking into account this situation and in view of the fact that the addition of energy improved milk production, Corado (1991) carried out a study utilizing rice bran as a supplement to grazing dairy cows receiving a constant level of *Erythrina poeppigiana* foliage equivalent to 0.5 % body weight. The results shown in Table 10 indicated that increasing the level of rice bran supplementation increased milk production. Although there were very little differences in crude protein and digestible energy intakes between the control diet and rice bran supplemented diet, equivalent to 0.02 % BW, daily milk yield increased from 8.8 kg/head to 9.7 kg/head, showing that bypass nutrients (protein and energy) improved milk production.

Alagon (1990) comparing *E. poeppigiana* foliage with conventional nitrogen sources (urea, fish meal and soybean meal) with different rumen degradation rates as protein supplements to dairy cows fed on chopped sugarcane plus rice bran, concluded that milk yield in cows supplemented with this tree foliage were similar to urea but inferior to soybean meal and fish meal (Table 11). However the urea diet resulted in inferior milk composition as well as cow weight loss compared with *the E. poeppigiana* diet. However when the same diets were used for growing heifers (Vasquez, 1991), daily gains of 763, 648 and 592 g per head were obtained for fish meal, E. poeppigiana and urea respectively. Camero (1991) showed that the supplementation of *Hyparrhenia rufa* hay (3% crude protein and 35% *in vitro* dry matter digestibility) with *E. poeppigiana* or *Gliricidia sepium* foliages improved milk yield as compared to urea

supplementation. The animals were in better body condition and had higher dry matter intakes with forage supplementation.

Table 7. The effect of increasing levels of fodder legume on productivity of cattle, sheep and goats.

Browse species	Animal species	Basal diet	Supplement level (%DM)	Voluntary intake (g kg^{-1})	Dietary DMD%	Weight change	Reference
Albizia chinensis	Goat	Barley straw	0*	18.9	45.9		Norton et al., 1992 (Australia)
			27	27.8	56.4		
			61	27.4	48.8		
			100	24.6	48.0		
Gliricidia	Cattle	Rice straw	0	27.0	47.0	-113	Doyle et al., 1986 (Thailand)
			10	31.0	46.0	-54	
			20	31.0	49.0	-94	
			33	33.0	55.0	10	
Gliricidia	Goat	Poor quality hay	0	21.8	45.0		Smith & van Houtert, 1987 (Nigeria)
			22	25.9	45.0		
			36	29.5	51.0		
			46	30.0	55.0		
Leucaena	Cattle	Natural grass	0	20.2	42.0	-20	Wahyuni et al., 1982 (Indonesia)
			20	26.1	44.0	290	
			40	28.8	46.0	540	
			60	28.8	44.0	590	
			100	22.0	51.0	310	
Leucaena	Sheep	Poor quality hay	0			-9	ILCA, 1987 (Ethiopia)
			15			15	
			27			37	
			45			53	
			59			65	
Leucaena	Sheep	Teff straw	0	24.9	47.3		Bonsi, 1995 (Ethiopia)
			33	31.9	48.6		
			50	33.8	50.4		
			66	33.7	55.3		
Leucaena	Goat	Maize stover	0	10.3	46.0		Banda and Ayoade, 1986 (Malawi)
			35	15.8	51.0		
			51	20.8	48.0		
			59	21.5	54.0		
Leucaena	Goat	Barley straw	0*	17.9	48.4	51	Norton et al., 1992 (Australia)
			33	29.5	60.5	71	
			65	30.9	57.2	66	
			100	27.0	62.1	46	
Sesbania sesban	Goat	Barley straw	0*	17.7	48.3	41	Norton et al., 1992 (Australia)
			33	28.7	60.9	47	
			66	31.7	64.1	63	
			100	27.8	63.9	9	

* Supplemented with 70g molasses + 30 g urea; DMD: dry matter digestibility

Table 8. Increases in milk production achieved in experiments where *Leucaena* was fed or grazed as a supplement to pure grass pastures.

Grass species	N rate (kg ha^{-1})	% increase in milk from *Leucaena*	Experimental details	Reference
Chloris gayana	115	7	fresh *Leucaena* fed in pens (2-4 kg/d)	Flores et al., 1979
Cynodon dactylon	-	16	6 hr *Leucaena* grazing	Saucedo et al., 1980
Cynodon plectostachyus	200	2	3-4 h *Leucaena* grazing	Ruan & Pino, 1981
Digitaria decumbens	239	33	2 hr *Leucaena* grazing	Suarez et al., 1987
Panicum maximum	150	12	Morning grazing *Leucaena*	Milera & Santana, 1989

Table 9. Effect of supplementation with *L. leucocephala* on milk yield.

	Level of *Leucaena* (kg fresh/day)		
	0	4	8
Intake kg/day			
napier grass	7.8	8.2	8.2
total	7.8	9.3	10.4
Milk yield (kg/day)	7.3	7.7	8.3
Live weight change			
Day 15-63 of lactation	-37	-10	-10
Day 64-112 of lactation	-18	-10	-10

Source: Muinga et al., 1992

Table 10. Crude protein and digestible energy intakes and milk production in grazing cows supplemented with *Erythrina poeppigiana* (0.5 %BW) and different levels of rice bran.

	Rice bran intake (% BW)			
	0	0.2	0.4	0.6
Crude protein intake (g/day)	1037	1071	1159	1263
Digestible energy intake (MJ/day)	102.1	100.8	111.7	120.9
Milk yield (kg/day)	8.7	9.7	9.9	10.5

Source: Corado (1991).

The supplementation of *Pennisetum purpureum* and green banana fruits with increasing amounts of *Erythrina poeppigiana*, *Morus* species and *Malvabiscus arborescens* foliages enhanced milk yields and daily gains in goats and lambs respectively. Although partial substitution effect of napier grass dry matter intake was detected, the total dry matter intake increased (Benavides, 1986; Esnaola and Rios, 1986). The addition of an energy source to grass diet supplemented with *Erythrina poeppigiana* improved daily milk production in goats (Samur, 1984). The crude protein to digestible energy ratio was shown by Castro (1989) to be more important than levels of foliage and energy for milk production by goats fed napier grass and supplemented

Table 11. Sugarcane intake and milk production and composition in cows fed sugarcane supplemented with *Erythrina poeppigiana* foliage and traditional nitrogen sources

	E. poeppigiana	Fish meal	Soybean meal	Urea
Sugarcane intake (%BW)	1.45	1.61	1.64	1.49
Milk yield (kg/day)	9.60	11.02	10.54	9.29
Milk composition (%)				
Total solids	12.58	12.43	12.48	11.96
Fat	3.63	3.37	3.50	3.59
Protein	3.27	3.42	3.38	3.05
Average daily gain (g/head)	468	892	887	461

Source: Alagon (1990)

with *Erythrina poeppigiana* foliage and green banana fruit. When *Erythrina poeppigiana* and sugarcane molasses were compared with commercial concentrates as protein supplements to milking cows grazing African star grass, the foliage supplementation consistently resulted in lower milk production and pasture dry matter intake (Abarca, 1989). Based on these results, it can be concluded that *E. Poeppigiana* is a good quality forage but not a concentrate.

Antinutritional factors in browses

Plants have co-evolved with predator populations of bacteria, insects, fungi and animals, and they have developed defence mechanisms which assist their survival. Leguminous trees and shrubs often have thorns, fibrous foliage and growth habits which protect the crown of the tree from grazing by ruminants. Many plants also produce chemicals which are not directly involved in the process of plant growth, but

act as deterrents to insect and fungal attack (Norton, 1994). Thus in some plants, the utility of leaves, pods and edible twigs of shrubs and trees as animal feed is limited by the presence of antinutritional factors (ANFs). The antinutritional factors may be defined as those substances generated in natural feedstuffs by the normal metabolism of species and by different mechanisms (e.g., inactivation of some nutrients, diminution of the digestive process or metabolic utilization of feed) which exert effect contrary to optimum nutrition (Kumar, 1992). Being an ANF is not an intrinsic characteristic of a compound but depends upon the digestive process of the ingesting animal and the adaptation of the animal to the ANF. The effects of ANFs vary with animal species, non-ruminants (pigs, poultry, horses) are usually more susceptible to toxicity than ruminants. The nature and action of ANFs in plants have been the subject of several reviews (Duke, 1977; Rosenthal and Jansen, 1979; Hegarty, 1982; Seawright et al., 1985; Barry and Blaney, 1987) in which attention was focused on pasture plants of commercial importance.

Table 12 provides a summary of the compounds which have been found in tree legume species which may affect animal productivity. The list of species is not exhaustive, and some compounds listed may not be toxic. Most antinutritional factors belong to a group of related compounds with similar mode of action. There are about 8,000 polyphenols, 270 non-protein amino acids, 32 cyanogens, 10,000 alkaloids and several saponins which have been reported to occur in various plant species (Kumar, 1992). Information on toxic substances in browses is well documented (Reed et al., 1985; Reed, 1986; Mueller-Harvey et al., 1987; D'Mello and Acamovic, 1989; Ash, 1990; D'Mello, 1992b). The effect of these toxins on animals may depend on the kind of pre-feeding treatment applied (Ahn et al., 1989), age of the plant foliage, site of the harvest or location (D'Mello and Acamovic, 1989) and the plant part fed (leaves, foliage or pods).

Amino acid derivatives

Mimosine, a non-protein amino acid (β-[N-(3-hydroxy-4-oxopyridyl)]-a-aminopropionic acid) structurally similar to tyrosine, occurs in a few species of Mimosa and all species of the closely allied genus *Leucaena*. The main symptoms of toxicity in ruminants are poor growth, loss of hair and wool, swollen and raw coronets above the hooves, lameness, mouth and oesophageal lesions, depressed serum thyroxine levels and goitre (Jones, 1979). The effect of mimosine can be reduced by heat treatment (Tangendijaja et al., 1990), by supplementation with amino acids (Rosenthal and Janzen, 1979) or with metal ions such as Fe^{2+}, Al^{3+} (D'Mello and Acamovic, 1989), and Zn^{2+} (Jones et al., 1978). It is now known that in areas where *Leucaena* is indigenous (Central America) and in parts of Asia, ruminants consuming *Leucaena* appear able

to degrade the ruminal metabolite of mimosine, 3-hydroxy-4(1H)-pyridone (DHP), to harmless end-products (Jones and Lowry, 1984). This capacity is associated with a specific bacterial population in the rumen on these adapted animals. These ruminal organisms capable of degrading DHP may be introduced into rumen of animals grazing *Leucaena* (Jones and Megarrity, 1986) thereby removing this constraint to increased use of *Leucaena*.

Table 12. A list of antinutritional factors found in some browse legume species.

Species	Plant part	Compound	Reference
Acacia aneura	leaf	condensed tannins, oxalate	Gartner & Hurwood, 1976
Acacia cambagei	leaf	cyanogenic glycoside (CG) CG hydrolase, oxalate	Cunningham et al., 1981
Acacia cyanophylla	leaf	condensed tannins	Reed et al., 1990
Acacia cana	leaf, stem	selenium	Cunningham et al., 1981
Acacia doratoxylon	leaf, stem	cyanogenic glycoside	Cunningham et al., 1981
Acacia georgina	leaf, stem	CG hydrolase (no CG)	Cunningham et al., 1981
		fluoroacetate	Cunningham et al., 1981
Acacia nilotica	pods	condensed tannins	Tanner et al., 1990
Acacia salicina	leaf, bark	tannins	Everist, 1969
	pods	saponins	Hall et al., 1972.
Acacia siberiana	leaves	hydrolysable tannins, CG	Tanner et al., 1990
Albizia chinensis	bark	echinocystic acid, glycosides oleanolic acid, sterols	Rawat et al., 1989
	leaf	condensed tannins	Ahn et al., 1989
Albizia lebbeck	flowers	various sterols	Asif et al., 1986.
	leaf	pipecolic acid derivatives	Romeo, 1984
	root	echinocystic acid	Sotelo et al., 1986
Calliandra calothyrsus	leaf	condensed tannins	Kaitho, 1992
Calliandra portoricensis	leaf	tannins, saponins, flavonoids glycosides	Aguwa & Lawal, 1987
Gliricidia sepium	leaf	pinitol	Calle et al., 1987.
	leaf	condensed tannins	Ahn et al., 1989
	leaf	coumarins, melilotic acid	Griffiths, 1962
	leaf	CG, nitrate	Manidool, 1985
	seed	canavanine, heat stable toxin	Sotelo et al., 1986
Leucaena leucocephala	leaf	mimosine	Hegarty et al., 1984
	leaf	condensed tannins	Ahn et al., 1989
	leaf	flavonol glycosides	Lowry et al., 1984
	leaf	saponins	Tangendijaja et al., 1990
Sesbania grandiflora	leaf, seed	tannins, glycosides	Andal & Sulochana, 1986
	flowers	methyl oleanolate	Kalyanaguranathan et al., 1985
Sesbania sesban	leaf	saponin	Dorsaz et al., 1988
	leaf	saponin, heat labile toxin	Shqueir et al., 1989
	leaf	saponin	Kholi, 1988
	leaf	tannin	Reed, 1986
Chamaecystisus palmensis	leaf	tannins/alkaloids	Borens & Poppi, 1990

Glycosides

(a) Cyanogenic glycosides

Cyanogenic glycosides occur in many Acacia species and when ingested and hydrolysed to free hydrogen cyanide (HCN), cause cyanide toxicity. Cyanide combines with haemoglobin in blood and inhibits respiratory enzymes, ultimately causing death. The response of ruminants to cyanogenic glycosides ingestion varies. In the rumen, HCN is converted to thiocyanate using available sulphur and thiocyanate is absorbed and excreted. Thiocyanate is a goitrogen, inhibiting the activity of the thyroid gland and often the effect of cyanogenic glycosides ingestion is seen as the development of goitre (Jones et al., 1978). Iodine supplementation overcomes this effect. The formation of HCN from this glycoside requires the presence of a specific hydrolytic enzyme in the plant tissue. Table 12 shows that both enzymes are not always present and, in the absence of the hydrolytic enzyme, cyanogenic glycosides are not toxic. Poor animal performance ascribed to *Acacia siberiana* pod feeding has been attributed to cyanogens (Tanner et al., 1990).

(b) Saponins and other sterols

Saponins are a group of triterpenes classified as terpenoids. They occur in alfalfa and many other different plants. They are characterized as substances with a bitter taste which foam in water and can cause haemolysis of red blood cells (Hanson et al., 1973). Saponins as well as other factors including proteins, pectins, saliva, rumen microflora, animal health, genetic differences and their interactions have been implicated in causing bloat (acute tympanites) in ruminants. Saponins increase surface tension of the rumen contents which contributes to a frothy bloat by entrapping bubbles of fermentation gas (Birk, 1969). Intraruminal and intravenous administration of alfalfa saponins induced experimental bloat (Lindahl et al., 1957a) and reduced ruminal motility (Lindahl et al., 1957b) in sheep. Sherma et al. (1969) observed that 4-7 weeks of feeding *Albizia stipulata* gave rise to toxic manifestation in sheep. The toxicity of broomweed is believed to be due to saponin content (Molyneux et al., 1980). Recent studies (Lu et al., 1987; Lu and Jorgensen, 1987) suggest that saponins inhibited microbial synthesis in the rumen and altered site and extent of nutrient digestion in ruminants. Factors such as genetic differences among animals, species of animals, biological activity of tannins and physiological status of the animal can influence the response to saponins. Within the species, certain animals showed more resistance to saponin action in terms of ruminal motility, development of bloat syndrome and irregularity of respiration rate (Lindhal and Davis, 1957). Microorganism

in the rumen act as a protective medium to saponin actions for the host animal. A long term effect of saponins would suggest a limitation for microorganism to degrade or inactivate saponins. Furthermore, it is also possible that the haemolytic action of saponins can seriously affect the growth of protozoa. The saponin, stigmasta - galactopyranoside has recently been isolated from *Sesbania sesban* seeds (Kholi, 1988). This saponin showed spermicidal and hemolytic activity. Tripathi and Rizvi (1985) also found that S. *sesban* extracts had anti-feeding activity against moth larvae. The authors reported that the leaves contain a saponin-like toxin and a heat labile factor.

A variety of secondary compounds have been isolated from *Albizia* species, some having biological activity. A range of sterols (raxerol, cycloartemol, campesterol, sitosterol) have been found in the flowers of *Albizia lebbeck* (Asif et al., 1986) and a saponin (echinocystic acid) was reported in root extracts (Shrivastava and Saxena, 1988). Triterpenic substances and glycosides of echinocystic acid (saponin) have been isolated from the bark of *A. chinensis*, and these bark extracts have been found to have molluscidal (Ayoub and Yankov, 1986), spermicidal (Rawat et al., 1989) and insecticidal (Tripathi and Rizvi, 1985) properties. Rahman et al. (1986) also reported that alkaloids from the seeds of *Albizia lebbeck* are fungicidal and cytotoxic to selected lines of cancer cells grown *in vitro*. As the name suggests, the neutral non-protein amino acid albizzine was first isolated from *Albizia lebbeck*, but no toxic activity has been reported.

Phytoestrogens

Plant products have been used in folk medicine from ancient times as aphrodisiacs, aids in child birth, abortifacients and promoters of fertility. Both increase and decrease in fertility in animals have also been attributed to specific estrogenic compounds in plants such as isoflavones and coumestans. However, plants may contain non-estrogenic compounds other which can affect reproductive performance. Isoflavonoids are widespread in legumes and the most important compounds are genistein, biochanin A, formonetin and the isoflavon equol. These compounds are precursors of phytoestrogens which have caused infertility and abortion in sheep grazing clover in Australia (Cox and Branden, 1974). However, Chadhokar (1982) fed diets containing 75% *Gliricidia* to pregnant sheep and found only beneficial effects of supplementation. Although clinical effects of phytoetrogens have been observed, the amounts of phytoestrogens in the environment are rarely sufficient to totally disrupt the reproductive process, so that subclinical impairment is more common.

Phenolics

Tannins are polymers whose monomeric units are phenols and occur almost in all vascular plants. They constitute one of the widespread and diverse group of secondary metabolites (Kumar, 1992). The two major structural classes are hydrolysable and condensed tannins. Hydrolysable tannins are characterised by having carbohydrate molecules partially or totally esterified with monomer, dimers or higher oligomers of phenolic groups like gallic acid (gallotannins) or ellagic acid (ellagitannins). Hydrolysable tannins are susceptible to hydrolysis by acids, bases or esterases to yield carbohydrate and the constituent phenolic acids (Haslam, 1989). Condensed tannins in nature are more widely distributed than hydrolysable tannins. Condensed tannins are oligomers and polymers of flavonoid units linked by carbon-carbon bonds that are not susceptible to cleavage upon hydrolysis. Condensed tannins are also called proanthocyanidins because they are degraded to form monomeric anthocyanidins (e.g., cyanidin, delphinidin) pigments upon heating in strong acid (Porter et al., 1986; Haslam, 1989). Anthocyanidin pigments are responsible for the wide array of colours in flowers, leaves, fruits, fruit juices and wines, and are responsible for astringency taste (Larwence, 1991; Horvath, 1981; Haslam, 1989).

The most commonly recognized property of tannins is that they bind proteins, a characteristic that has been recognized for centuries. Nevertheless, the tannin-binding mechanisms and the nutritional effects of this binding are not fully elucidated (Reed et al., 1990; McLeod, 1974; Reed et al., 1982). Historically it was believed that tannins bind and precipitate all proteins nonspecifically, but it is now well recognized that tannin-proteins are specific and depend on the structure of both the protein and tannin (Hagerman and Klucher, 1986). Condensed tannins have a more profound digestibility-reducing effect than hydrolysable tannins, whereas the latter may cause varied toxic manifestations due to hydrolysis in the rumen. The binding of condensed tannins and proteins inhibits fermentation of structural carbohydrates (D'Mello, 1992a) in the rumen and reduces protein availability to rumen microbes. The detrimental effects of tannins (Herit and Ford, 1982; Barry and Manley, 1984, McSweeney et al., 1988, Woodward and Reed, 1989) and mimosine (D'Mello and Taplin, 1978; Acamovic et al., 1982; D'Mello, 1992b) have been reviewed in various articles.

Recent studies have shown that some oligomeric proanthocyanidins are also associated with sugars by covalent linkage or C-ring substitution during development and formation of fruits, seed coat and bark (Porter, 1989; Porter, 1992). Starch-tannin interactions show different degrees of binding in comparison to cellulose-tannin interactions (Mueller-Harvey et al., 1988). It is not clear whether pH plays a role in these tannin-carbohydrate interactions, yet there is some evidence for an increased affinity at higher pH values (Mueller-Harvey and McAllan, 1992).

The ability of an animal to tolerate tannins depends on the animals adapted capability and on the type of tannins involved (Hagerman et al., 1992). Some animal characteristics that influence the impact of dietary tannins include the type of digestive tract, feeding behaviour, body size (higher turnover in small ruminants) and detoxification mechanisms. Subsequently, the content and the type of tannin mixtures in the diet jointly determine the chemical reactivity of the tannin that influences the direction of the effect. Consequently, tannins in forage legumes and browses fed to ruminants have both negative and positive effects on nutritive value (Reed et al., 1990; Barry and Blaney, 1987). A high tannin content decreases feed consumption due to impaired palatability, digestibility of dietary protein and carbohydrate, reduction of nitrogen absorption resulting in higher faecal nitrogen output, lower urine nitrogen excretion, and a reduction in nitrogen retention (Barry and Manley, 1984; Reed et al., 1990; Barry and Duncan, 1984; Barry et al., 1986; Reed, 1995)

A number of methods have been tried to overcome the deleterious effects of tannins (Kumar and Singh, 1984). Increases in voluntary intake of high tannin forage species have been observed when adsorbents such as polyethylene glycol (PEG) or polyvinylpyrrolidone (PVP) are sprayed on such forages or added to the diet. Tannins bind more strongly to these tannin-binding materials than to protein (Kumar and Singh, 1984). Their incorporation has been reported not only to increase feed palatability but also to improve dry matter and protein digestibilities resulting in greater weight gain and wool production in sheep (Kumar and Vaithiyanathan, 1990). Three months feeding of *Prosopis cineraria* leaves and *Cenchrus* species (50:50) with 1% urea has been found to maintain adult sheep (Russell and Lolley, 1989). In such a feeding system, urea not only provided extra nitrogen to the animals but also deactivated the leaf tannins. Recent research with rumen bacteria isolated from goats fed *Desmodium ovalifolium* has resulted in the discovery of two unique rumen bacteria. These organisms were capable of degrading hydrolysable tannins and tolerated high levels of condensed tannins without detrimental physiological effects (Nelson et al., 1995). These types of rumen bacteria will respond more efficiently to the presence of tannins, either by using these compounds as an energy source or by strategically tolerating them in high concentration. They can be used as inoculants to overcome the detrimental effects of tannins in ruminants.

Some tannin-consuming animals secrete tannin-binding proteins in saliva (Mehansho et al., 1987). The tannin-binding capacity of the salivary mucins is generally related to a high proline content and the feeding habits of the animal (Robbins et al., 1991; McArthur et al., 1991; Hanley et al., 1992; McArthur et al., 1993). Both the amount and effectiveness of the tannin-binding agents in saliva decrease in these animals in the following order: mule deer, goat, sheep and cattle (Austin et al., 1989). The saliva of browsing ruminants, like deer, contains more proline-rich proteins

(PRP) than that of a grazing ruminant. There are claims that there are no salivary PRP in saliva of sheep or cattle (Austin et al., 1989). However, animals may adapt upon prolonged feeding. Consumption of a high tannin diet stimulates development of the salivary gland to permit more PRP production (Butler, 1989). For example, goats which are browsers and which often consume high levels of tannins have enlarged salivary glands and produce significant amounts of PRP (Provenza and Malechek, 1984).

Methods to alleviate the effects of anti-nutritional factors

The uncertainty of quantification and the imperfectly understood biological effects of anti-nutritional factors impede the development of methods to alleviate their effects. The simplest approach of dilution (supplementation) may certainly reduce the risk of toxicity but simultaneous nutritional benefits may not accrue. Moreover the required degree of dilution is difficult to recommend because of uncertain quantification. Toxicity depends upon the concentration of the deleterious compounds in the fodder and the rate at which the forage is eaten. "An amount of the plant eaten quickly, say in one hour, could be fatal, whereas the same amount of plant material eaten slowly, for example, over a five hour period, would be harmless" (Storrs, 1982).

Several studies indicate that tannin-rich leaves, in combination with concentrate rations, could be fed to animals without any adverse effect (Raghavan, 1990). This was so because animals consumed protein in excess of their requirement from the concentrate and therefore, the antinutritional effects of tannins were masked.

The utility of management practices involving lopping/harvesting of tree leaves at times when the concentration of anti-nutritional factors are lowest is limited because pattern of changes in concentration of various allelochemicals may not be the same. It has also been noted that, as leaves mature, both the anti-nutritional factors and nutrient content decreases (Singh, 1982). Another approach is supplementing animals PVP or PEG treated leaves during acute feed shortage to avoid livestock losses. These cannot be used routinely because of prohibitive cost, however metal ions and urea supplementation could be recommended to farmers after thorough assessing their alleviating effects against high possible reported concentration of anti-nutritional factors. The efficacy of wilting in reducing the risk of cyanide toxicity needs to be tested before it is recommended to farmers. Simple washing with water removes the soluble anti-nutritional factors but nutrients also leach out.

Rumen bacteria and fungi capable of degrading lignin have been isolated. Anaerobic degradation of flavonoid and tannins by mixed rumen microbes has also been demonstrated. Moreover, it has been shown that the transfer of rumen fluid from animals in Hawaii to Australian ruminants resulted in complete elimination of toxic effects of mimosine and the bacteria involved in such effects, have been identified

(Allison et al., 1990). Evidence also exists that rumen microbes can be genetically manipulated (Russell and Wilson, 1988). These findings imply that future research may be drawn towards identification of the various anaerobic and gut microbes capable of dissimilating anti-nutritional factors, testing the survivability of organisms in the rumen and investigating whether the dissimilation is plasmid encoded, so that genetic manipulation of rumen bacteria can be affected for the useful fermentation of anti-nutritional factors. Attempts at detoxification of these browses include genetic selection, heat treatment (D'Mello, 1982), wilting and leaching (Szyszks et al., 1983). A number of methods are used by farmers to overcome or reduce palatability or toxicity problems caused by anti-nutritional factors. Wilting, drying and dilution of the problem feed with other feeds are common practices (Smith, 1992).

Conclusions and recommendations

Browse utilization and the constraints to their efficient utilization in the nutrition of herbivores have been reviewed. In addition, the chemical composition and nutritive value of the shoots, leaves and pods of browse species have been considered. It is clear that browses have a distinct advantage over tropical grasses in terms of their superior nutritional value particularly during the dry season.

Although many different and some potentially dangerous compounds have been isolated from many of the potentially useful fodder trees, little is known about the specific effects of these compounds on ruminant metabolism. The intense interest in *Leucaena* has generated research which first identified the regional problem of mimosine and DHP toxicity, and then proceeded to provide a practical solution to the management of this problem. Similarly, fodder trees of potential value but with the anti-nutritional properties should be addressed. Tannins are considered as the most important deleterious principles in browses. It is therefore necessary to carry out more research to determine appropriate methods of alleviating these deleterious affects in order to upgrade the quality of the protein value of these feeds. The long term effect of these substances on rumen microbes and the host animal need to be investigated jointly by nutritionists, rumen microbiologists, toxicologists, phytochemists and physiologists.

For optimum utilization of browses, it is essential that details of agronomic characteristics, palatability and nutritive value of the prominent species are determined. In plant introduction and range evaluation programs, there is a need to rapidly screen large numbers of plants for nutritive value, palatability and potential toxicity. Studies addressing the quantity of bypass protein, protein digestion in the small intestine and endogenous protein loss should also receive attention.

In ruminant feeding, considerable evidence exists of beneficial responses to

production due to the use of browse supplements in terms of live weight and milk production. There is a need for a wider application of these research results in large scale on-farm trials. There is also a need for socio-economic survey(s) to evaluate the role of multipurpose trees in mixed farming systems and especially their role as sources of fodder. Diagnostic surveys should pay particular attention to the technical, political and socio-economic aspects of incorporating browses in farming systems. Interdisplinary priority research is required in the following areas:

- Evaluation of local species of trees and shrubs currently used widely by farmers, but for which there is negligible information. In identification of species with high potential as fodders, farmers participation and knowledge should be used.
- Development of a set of standard methods that can be used to screen large number of browse for their palatability and voluntary intake.
- Relationships between chemical composition, rumen degradation characteristics, gas production parameters, palatability and dry matter intake in browses.
- Response curves relating inputs of foliages and animal performance on different basal diets, and development of appropriate optimum supplementation rates.
- Protein metabolism of animals supplemented with browses.
- Detailed studies on secondary plant compounds, their effect on the animal and rumen micro-organisms.
- Studies on the effects of browses on animal health and reproduction over longer periods.
- Use of mixtures of leaves from different species to optimise tannin contents and thus improve by-pass protein characteristics.

Research and development activities need to ensure that the use of these supplements are cost-effective and economically justifiable in all production systems.

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Chapter 2

Palatability of multipurpose tree species: effect of species and length of study on intake and relative palatability by sheep

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Published in: Agroforestry Systems (1996) 33:249-261.

Palatability of multipurpose tree species: effect of species and length of study on intake and relative palatability by sheep

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Abstract

The potential forage value and appropriate length of study on intake and relative palatability ranking of 40 multipurpose tree species (MPTs) were determined using 24 sheep blocked on live weight and age. As the MPTs had different dry matter contents, intakes were also expressed as a ratio of quantity offered (A_i/D_i). Using daily *Eragrostis tef* straw offer (TD) and intake (T), relative palatability indices were calculated as

$$R_i = (A_i/D_i)/(T_i/TD_i).$$

There was a significant ($P<0.0001$) decrease in correlation of intake measured in day 1 and subsequent days ($r=0.88$, 0.81 and 0.79 for days 2-4, days 5-8 and days 9-12, respectively). A similar trend was observed on corresponding palatability indices. Individual animal preference and blocking did not affect intake and palatability indices significantly ($P>0.05$), however significant ($P<0.0001$) tree species differences were observed. Results on linear regression, correlation coefficients, palatability ranking and standard errors of means (adjusted palatability indices) indicate that, if palatability is done to predict long-term intake of MPTs, at least 5 days are appropriate in palatability assessment for sheep.

Using mean palatability index (days 2-12), the MPTs were grouped into four clusters. The MPTs such as *Leucaena leucocephala* and *Sesbania sesban* which are known to have good nutritive value had high palatability. In the same classification group, there were less known species such as *Acacia venosa, A. persiciflora, A. melanoxylon, A. hockii, A. polyacantha, Tamarindus indica, Chamaecytisus palmensis, Tipuana tipu, Indigofera arrecta* and *Atriplex nummularia*. *Flemingia macrophylla, Erythrina abyssinica, Acacia salicina, Acacia coriacea, Albizia schimperiana, Ceratonia siliqua, Casuarina glauca* and *Erythrina burana* had poor palatability. These species seem to have little forage value for animals with short-term adaptation periods. *Gliricidia sepium* and *Calliandra calothyrsus* although currently being used by farmers had a medium palatability ranking.

Key words: Palatability, multipurpose trees and shrubs, intake, sheep

Introduction

Multipurpose trees and shrubs (MPTs) are defined as all woody perennials that are deliberately grown to provide more than one significant contribution to the production and/or service functions of a land use system [Burley and von Carlowitz, 1984]. MPTs have a high potential value as a source of feed and protein supplement for domestic livestock and wildlife. Their contribution is highest in the arid and semi arid areas, where the pattern and intensity of rainfall leads to fluctuations in forage quantity and quality. The management and use of MPTs requires knowledge of their palatability and nutritive value.

Many MPTs have been documented as useful animal fodders and lists of those that are of potential value as fodders have been published [Le Houèrou, 1980; ILCA, 1985; Brewbaker, 1986].The most commonly used species come from the genera *Acacia, Albizia, Calliandra, Desmanthus, Desmodium, Gliricidia, Leucaena, Prosopis and Sesbania* [Brewbaker, 1986]. Most of the high potential MPTs are among the over 12,000 forage plant accessions maintained by the Genetic Resources section of the International Livestock Research Institute.

A number of trials have been carried out to study palatability of browses [Johnston, 1988; Rutagwenda et al., 1990]. Olson, (1991) pointed out that conventional methods commonly used to assess classic forage preference (oesophageal fistula technique, stomach content analysis and faecal analysis) are not convenient for screening a wide range of browses, as they are laborious, costly and complicated. Methods based on direct feeding observation and measurement of intake of plant species either at pasture or in stall experiments seem to be more suitable for palatability studies. However, the choice of trial length becomes important when observations are made on direct feeding. Several durations have been reported; some trials have been limited to less than 30 min [Cannon et al., 1987], others to 2 h [Rios et al., 1989] or one day [Mill et al., 1990] after offering feed. Trials lasting the entire grazing season, or even over 1 year have also been reported [Lusigi et al., 1984]. Ben Salem et al. (1994) observed that 5 days palatability assessment gave the most accurate prediction of intake for sheep. Moreover, animals seem to adapt to initially unpalatable feeds in long-term palatability trials [Ben Salem et al., 1994]. Therefore the objectives of this trial were to determine the potential forage value of 40 MPTs and appropriate length of study that is needed in order to establish a stable relative palatability ranking by sheep.

Materials and methods

The study was carried out at the International Livestock Research Institute's (ILRI) seed multiplication site at Zwai in the Rift Valley of Ethiopia (8°00'N; 38°45'E) at an altitude of 1650 m above sea level, with an average bimodal rainfall of 600 mm. The soil at the site was loamy sand and is classified as a vitric andosol with a pH (H_2O) of 8.05 [Kamara and Haque, 1988]. Forty multipurpose tree and shrub species (MPTs) were selected from those already established on the site based on quantity of fodder assessed to be available to last the duration of the experiment.

Twenty four wethers (±SD), 1.1 ±0.12 years old and 18.9 ±1.88 kg live weight, bought from the nearby livestock markets, were blocked into three groups on live weight and age. The animals were housed in a roofed and half-walled shed with individual feeding pens . Each animal was provided with a feeding trough divided into six separate compartments to accommodate test feeds. The sheep underwent standard quarantine procedure for 21 days; adaptation to confinement feeding commenced after 15 days of quarantine. Data collection took 12 days which were divided into three periods of 3-4 days. The 40 MPTs were randomly grouped into sets of five and allocated to the sheep in each block. The MPTs sets were different between blocks.

Feeds and feeding

The sheep were fed grass hay, wilted *Aeschynomene elaphroxylon* and *Sesbania* spp leaves ad-libitum during the adaptation period of 7 days. During the data collection period, all animals were fed 0.4 kg teff straw (*Eragrostis tef*) and the corresponding wilted MPTs foliage (0.4 kg wilted weight per species). Fresh leaves were harvested and stored in a cold room for feeding the next day. Feeds were offered at 08:00 h daily. The order of placement of the test feed in the feed trough was randomized every day to avoid 'habit reflex'. Water was provided adlibitum using a rubber bucket.

Measurements, calculations and statistical analysis

The feeds offered and refused were recorded for each animal on a daily basis and samples kept separately according to species and animal. Dry matter was assayed on the offered (Table 1) and refused feed by drying at 105°C for 24 h.

The following variables were determined following the procedure described by Ben Salem et al. (1994):

- T_1 : teff straw intake on day 1;
- T_2, T_3, T_4, T_5 : average teff straw intake on days 2-4, 5-8, 9-12 and 2-12, respectively;
- A_1 : MPTs intake on day 1;

- A_2, A_3, A_4, A_5 : average MPTs intake on days 2-4, 5-8, 9-12 and 2-12, respectively;
- TD_1 : quantity of teff straw offered on day 1;
- TD_2, TD_3, TD_4, TD_5 : average quantity of teff straw offered on days 2-4, 5-8, 9-12 and 2-12, respectively;
- D_1 : quantity of MPTs offered on day 1;
- D_2, D_3, D_4, D_5 : average quantity of MPTs offered on days 2-4, 5-8, 9-12 and 2-12, respectively;

Relative palatability indices (R) which described palatability of individual MPTs in relation to teff straw were calculated as:

$R_1 = (A_1/D_1)/(T_1/TD_1)$

$R_2 = (A_2/D_2)/(T_2/TD_2)$

$R_3 = (A_3/D_3)/(T_3/TD_3)$

$R_4 = (A_4/D_4)/(T_4/TD_4)$

$R_5 = (A_5/D_5)/(T_5/TD_5)$

The MPTs were ranked using these indices as animal preference. The SAS (1987) Institute statistical package was used for analysis of variance, calculations of correlation coefficients and cluster analysis. Exploration of standard deviations for species association effect was also carried out.

Results

Dry matter intake and relative palatability indices of MPTs to teff straw are shown in Table 1. Sheep consumed more teff straw than foliage of any of the MPTs . However, they ate less teff straw than was offered. Some of the MPTs offered were consumed completely (e.g. *Sesbania sesban* var. bicolor). An increasing trend in daily intake of *Sesbania sesban*, *Leucaena leucocephala, Acacia horrida, Acacia melanoxylon* and *Leucaena pulverulenta* was observed from day 1. The reverse was true for *Erythrina burana, Erythrina abyssinica, Moringa stenopetala, Atriplex halimus, Acacia microbotrya* and *Albizia schimperiana. Indigofera arrecta* fodder was enough for 8 days only.

Individual animal preference and blocking did not affect intake and palatability indices significantly ($P>0.05$), however significant ($P<0.0001$) tree species differences were observed. There was a significant ($P<0.0001$) decrease in correlation of intake measured in day 1 and subsequent days ($r=0.88$, 0.81 and 0.79 for A_2, A_3 and A_4, respectively). (Table 2). A similar trend was observed for R_1, R_2, R_3 and R_4 palatability indices. High correlations of palatability indices were obtained between R_5 and R_2 ($r=0.90$), R_5 and R_3 ($r=0.98$), R_5 and R_4 ($r= 0.96$). R_5 was poorly correlated to R_1 ($r=0.5$). Three of the animals consumed relatively more of all the feeds provided while one sheep with the lowest body weight consumed consistently less, leading to high mean standard deviation (>0.50) of the MPTs these animals were offered.

Table 1. Dry matter content (g/kg), intake and palatability indices of multipurpose trees.

species	DM	Intake (g DM day^{-1})					Palatability indices				
		A_1	A_2	A_3	A_4	A_5	R_1	R_2	R_3	R_4	R_5
Acacia horrida	327	78	108	142	142	133	0.68	0.76	1.06	1.08	0.99
Acacia melanoxylon	378	49	108	118	123	117	0.42	1.04	1.27	1.21	1.18
Acacia salicina	404	16	11	21	23	19	0.15	0.11	0.20	0.21	0.18
Acacia sieberiana	388	115	85	93	105	95	1.07	0.91	0.88	1.04	0.94
Acacia dolichocephala	402	47	37	62	41	48	0.58	0.39	0.56	0.34	0.43
Acacia polyacantha	697	121	72	144	118	115	1.70	0.66	1.24	1.11	1.04
Acacia hockii	367	161	101	122	103	109	1.43	1.03	1.11	1.02	1.05
Acacia venosa	360	146	96	135	122	120	1.46	1.09	1.33	1.34	1.27
Acacia persiciflora	308	115	121	142	139	135	1.39	1.11	1.27	1.28	1.23
Acacia coriacea	337	39	10	12	17	13	0.44	0.13	0.10	0.16	0.13
Acacia saligna	353	13	31	81	88	70	0.14	0.27	0.82	1.01	0.74
Acacia microbotrya	334	81	9	33	7	17	0.63	0.07	0.39	0.07	0.19
Albizia schimperiana	356	103	11	16	10	13	1.39	0.13	0.14	0.10	0.12
Atriplex nummularia	212	49	72	70	64	68	0.94	1.11	1.16	1.08	1.12
Atriplex rhagodiodes	187	42	29	53	52	46	0.65	0.45	0.91	0.99	0.81
Atriplex halimus	186	100	51	63	48	54	1.52	0.90	0.93	0.77	0.86
Calliandra calothrysus	393	127	133	114	91	111	1.39	1.15	0.92	0.73	0.91
Casuarina cunninghamiana	505	82	72	67	36	57	0.62	0.60	0.38	0.20	0.38
Casuarina equisetifolia	453	37	73	109	89	92	0.27	0.69	0.80	0.75	0.75
Casuarina glauca	477	43	14	13	18	15	0.33	0.10	0.09	0.11	0.10
Ceratonia siliqua	409	17	7	27	6	14	0.13	0.05	0.23	0.05	0.12
Chamaecytisus palmensis	334	127	132	139	126	132	1.16	1.25	1.22	1.17	1.21
Entada abyssinica	339	98	53	65	57	59	1.18	0.66	0.60	0.57	0.61
Enterolobium cyclocarpum	386	55	27	52	60	48	0.48	0.22	0.61	0.60	0.50
Erythrina abyssinica	223	45	18	12	6	12	0.56	0.30	0.20	0.11	0.19
Erythrina bentipoeme	209	61	56	65	50	57	0.78	1.00	0.91	0.80	0.90
Erythrina burana	356	23	5	5	5	5	0.45	0.08	0.08	0.08	0.08
Flemingia macrophylla	254	60	8	37	38	30	0.52	0.07	0.28	0.29	0.23
Gliricidia sepium	283	65	39	40	43	41	1.01	0.52	0.49	0.51	0.50
Indigofera arrecta	377	111	111	86	*	105	1.92	1.16	1.11	*	1.15
Leucaena pulverulenta	373	55	63	152	141	124	0.55	0.76	1.24	1.19	1.09
Leucaena pallida	370	123	128	152	135	139	1.40	1.22	1.28	1.32	1.28
Leucaena leucocephala	239	94	98	139	145	130	0.68	0.74	1.05	1.10	0.99
Moringa stenopetala	416	82	64	66	65	65	1.16	1.03	0.83	0.80	0.88
Samanea saman	221	43	43	35	55	44	0.32	0.46	0.39	0.48	0.44
Sesbania goetzei	311	64	33	54	52	48	0.97	0.65	0.79	0.84	0.77
Sesbania sesban var. bicolor	254	104	100	104	96	100	1.36	1.41	1.44	1.54	1.47
Sesbania sesban	274	96	123	122	125	123	0.96	1.23	1.19	1.21	1.21
Tamarindus indica	401	112	109	110	99	106	1.33	1.19	1.31	1.37	1.30
Tipuana tipu	192	163	118	139	167	143	1.21	1.06	1.14	1.34	1.19
Eragrostis tef (straw)	931	271	296	318	321	313	1.00	1.00	1.00	1.00	1.00
LSD	69.7	66.7	67.3	75.2	61.3		0.63	0.58	0.44	0.51	0.45

LSD : least square difference; n=3 ; $R_i = (A_i/D_i)/(T_i/TD_i)$; A_i : MPTs intake; D_i : MPTs offered; T_i: teff straw intake; TD_i : teff straw offered; $_i$: 1 (day 1), 2 (day 2-4), 3 (day 5-8), 4 (day 9-12) and 5 (day 2-12). * : feed was enough for eight days.

Table 2. Correlation coefficients between intake and palatability indices of multipurpose trees.

Parameters	A_1	A_2	A_3	A_4	A_5	R_1	R_2	R_3	R_4	R_5
A_1	1.00	0.88*	0.81*	0.79*	0.84*	0.51*	0.47*	0.37*	0.37*	0.41*
A_2		1.00	0.94*	0.92*	0.96*	0.31*	0.60*	0.50*	0.48*	0.55*
A_3			1.00	0.98*	0.99*	0.23**	0.50*	0.53*	0.52*	0.54*
A_4				1.00	0.99*	0.22**	0.47*	0.51*	0.54*	0.54*
A_5					1.00	0.25**	0.52*	0.52*	0.53*	0.55*
R_1						1.00	0.57*	0.43*	0.42*	0.50*
R_2							1.00	0.84*	0.76*	0.90*
R_3								1.00	0.93*	0.98*
R_4									1.00	0.96*
R_5										1.00

*, ** : level of significance for 0.0001 and 0.01 probability, respectively

$R_i = (A_i/D_i)/(T_i/TD_i)$; A_i : MPTs intake; D_i : MPTs offered; T_i: teff intake; TD_i : teff offered; $_i$: 1 (day 1), 2 (day 2-4), 3 (day 5-8), 4 (day 9-12) and 5 (day 2-12).

Linear regression equations of MPTs dry matter intake were:

$A_5 = 5.307 + 0.981A_1$ (RSD=57.36, r^2=0.70, P<0.0001

$A_5 = 12.792 + 0.986A_2$ (RSD=28.29, r^2=0.93, P<0.0001),

$A_5 = -3.925 + 0.979A_3$ (RSD=11.53, r^2=0.99, P<0.0001) and

$A_5 = 4.813 + 0.940A_4$ (RSD=16.64, r^2=0.97, P<0.0001).

This indicated that the best relationship existed between A_5 and A_3 and a poor relationship between A_5 and A_1. This was reflected in relative palatability ranking of R_1 as compared to R_2, R_3, R_4 and R_5 (Table 3). Consequently, R_1 gave different rank positions from R_2, R_3, R_4 or R_5 .

Using the R_5 palatability index, the MPTs clustering solution based on pseudo-T^2 statistics was a 4-cluster classification (Table 3). The cluster means were 1.17 $\pm$0.13, 0.84 $\pm$0.08, 0.48$\pm$0.08, 0.15 $\pm$0.05 for clusters 1, 2, 3 and 4, respectively. High cluster means reflect high palatability. Six *Acacia* spp (*A. venosa, A. persiciflora, A. melanoxylon, A. hockii, A. polyacantha and A. horrida), three Leucaena spp (L. leucocephala, L. pallida and L. pulverulenta), two Sesbania sesban* accessions and *Chamaecytisus palmensis* were classified in cluster one. *Flemingia macrophylla* and *Ceratonia siliqua* were classified in the cluster of least palatable MPTs, while, *Gliricidia sepium* was classified in cluster three.

The chances of misclassifying species when R_1, R_2, R_3 and R_4 indices instead of R_5 were used are shown in Table 4. Percentage misclassification decreased in the order: $R_1 > R_2 > R_4 > R_3$ (50.0, 32.5, 7.8, 2.5%, respectively).

Table 3. Relative palatability ranking of MPTs on R_1, R_2, R_3, R_4 and R_5 and cluster groups

species	R_1	R_2	R_3	R_4	R_5	cluster[$]
Sesbania sesban var. bicolor	10	1	1	1	1	1
Tamarindus indica	11	5	3	2	2	1
Leucaena pallida	6	4	4	5	3	1
Acacia venosa	4	9	2	3	4	1
Acacia persiciflora	8	36	5	6	5	1
Chamaecytisus palmensis	15	2	9	10	6	1
Sesbania sesban	20	3	10	8	7	1
Tipuana tipu	12	10	12	4	8	1
Acacia melanoxylon	35	11	6	7	9	1
Indigofera arrecta	1	6	13	[a]	10	1
Atriplex nummularia	21	8	11	13	11	1
Leucaena pulverulenta	30	18	8	9	12	1
Acacia hockii	5	12	14	16	13	1
Acacia polyacantha	2	15	7	11	14	1
Eragrostis tef	18	15	17	18	15	-
Acacia horrida	23	19	15	14	16	1
Leucaena leucocephala	24	20	16	12	17	1
Acacia sieberiana	16	16	22	15	18	2
Calliandra calothrysus	7	7	19	25	19	2
Erythrina bentipoeme	22	14	20	21	20	2
Moringa stenopetala	14	13	23	22	21	2
Atriplex halimus	3	17	18	23	22	2
Atriplex rhagodiodes	25	28	21	19	23	2
Sesbania goetzei	19	24	26	20	24	2
Casuarina equisetifolia	38	21	25	24	25	2
Acacia saligna	40	31	24	17	26	2
Entada abyssinica	13	23	28	27	27	3
Gliricidia sepium	17	26	30	28	28	3
Enterolobium cyclocarpum	32	32	27	26	29	3
Samanea saman	37	27	31	29	30	3
Acacia dolichocephala	28	29	29	30	31	3
Casuarina cunninghamiana	27	25	33	33	32	3
Flemingia macrophylla	31	39	34	31	33	4
Erythrina abyssinica	29	30	36	35	34	4
Acacia microbotrya	26	40	32	39	35	4
Acacia salicina	39	35	37	32	36	4
Acacia coriacea	34	33	39	34	37	4
Albizia schimperiana	9	34	38	37	38	4
Ceratonia siliqua	41	41	35	40	39	4
Casuarina glauca	36	37	40	36	40	4
Erythrina burana	33	38	41	38	41	4

Accession numbers in parenthesis; [$] : clusters are based on R_5 index; $R_i = (A_i/D_i)/(T_i/TD_i)$; A_i : MPTs intake; D_i : MPTs offered; T_i: teff intake; TD_i : teff offered; $_i$: 1 (day 1), 2 (day 2-4), 3 (day 5-8), 4 (day 9-12) and 5 (day 2-12); [a] : feed was enough for eight days.

Table 4. Change in cluster membership due to the use of R_1, R_2, R_3 and R_4 indices for classification rather than R_5.

Re-classification indices	Clusters based on R_5	New clusters based on reclassification indices				% misclassification
		1	2	3	4	
R_1	1	9[$]	1	3	3	17.5
	2	1	6[$]	2	0	7.5
	3	1	2	2[$]	1	10.0
	4	2	2	2	3[$]	15.0
R_2	1	12[$]	0	0	4	10.0
	2	0	8[$]	1	0	2.5
	3	0	1	3[$]	2	7.5
	4	3	1	1	4[$]	12.5
R_3	1	16[$]	0	0	0	0.0
	2	0	8[$]	1	0	2.5
	3	0	0	6[$]	0	0.0
	4	0	0	0	9[$]	0.0
R_4	1	14[$]	0	0	1	2.6
	2	0	8[$]	1	0	2.6
	3	0	1	5[$]	0	2.6
	4	0	0	0	9[$]	0.0

[$] : refer to number of species that fall in the same clusters as in R_5.

Discussion

Palatability is a complex phenomenon influenced by animal, plant and environmental factors. Palatability as defined by Marten (1978) is a plant characteristic(s) eliciting a proportional choice among two or more forages conditioned by plant, animal and environmental factors which stimulate a selective intake response by the animal. This characteristic(s) may also be described in terms of acceptability, preference, selective grazing, and relish conditioned by sensory impulse. The phenomenon of palatability does not always involve a choice, in that an animal may find a specific feed acceptable or unacceptable. This was clearly observed during the adaptation period when sheep were offered, at the same time, *Sesbania* spp, *Aeschynomene elaphroxylon* and grass hay adlibitum. Most of the sheep showed no preference for either of the browses. The intake increment observed for a number of species in this study may be explained by an adaptation effect of the animals. Species which are known to be palatabie like *Leucaena* spp and *Sesbania sesban* were less preferred on the first day but were relished over time. The differences between the intake of MPTs by sheep could partly be due to the different dry matter contents of the forage of MPTs evaluated.

Plant factors that influence forage palatability to animals are species, intra-specific variation, chemical composition, morphology or physical traits, succulence or maturation, availability in non-controlled situations and form of forage [Marten, 1978].

The probable cause of low palatability of some of the MPTs could be attributed to these factors. For example, *Calliandra calothyrsus* [Kaitho, 1992] and *Chamaecytisus palmensis* [Varvikko and Khalili, 1993] have been reported to have poor palatability in dry form in both sheep and cattle, but had high palatability when offered in the wilted form as in this trial. Thus it seems that the form of presentation (wilted vs dried) does affect palatability. This is similar to the observation of Palmer and Schlink (1992) that wilted *Calliandra* was more rapidly digested than the dried form and this was the cause of the 37% difference observed in the intake of wilted vs dried *Calliandra*.

According to Personius et al. (1987), herbivores are able to detect some toxic compounds by smell before eating or immediately after the first bite. For some of the MPTs in this study, intake decreased with time over the 12 day experimental period suggesting that animals could have developed some reflex against inhibitory factors to taste, smell, volatile compounds or astringency, which could elicit the observed response. Phenolics, alkaloids, tannins and aromatic compounds are some chemical compounds known to alter palatability [Marten, 1978]. However, some of the species had consistently low palatability throughout the trial period hence may have low fodder value.

All the *Leucaena* species had high palatability. This is in general agreement with other studies [Palmer et al., 1991; Mtenga et al., 1994]. *Sesbania sesban, Acacia venosa, A. persiciflora, A. melanoxylon, A. hockii, A. polyacantha, Tamarindus indica, Chamaecytisus palmensis, Tipuana tipu, Indigofera arrecta* and *Atriplex nummularia* were classified in the same group as *Leucaena* species with high acceptability. The low palatability of *Gliricidia sepium* in this study is similar to observations made by Carew (1983). The odour of the leaves has been implicated in this initial reluctance of animals to eat Gliricidia (Brewbaker, 1986). *Flemingia macrophylla, Erythrina abyssinica, Acacia salicina, Acacia coriacea, Albizia schimperiana, Ceratonia siliqua, Casuarina glauca* and *Erythrina burana* had poor palatability. This could have been due to antinutritional factors such as high fibre constituents (*Casuarina* spp, *Flemingia macrophylla, Erythrina burana*), odours (*Albizia schimperiana*) or tannins (*Acacia salicina, Acacia coriacea, Ceratonia siliqua*).

Differences in relative palatability of species within the genera *Acacia, Atriplex, Erythrina, Casuarina* and *Sesbania* have important implications in selecting suitable species within a genus. It is therefore possible to select high yielding and palatable species within a genus with good fodder value. Even within the same *Gliricidia* species, Larbi et al. (1993) observed that there were differences in palatability of provenances.

Preference for a species also varies with associated species and nature of associated feeds in the diet [Marten, 1978]. In this study, each species was compared with 12 others randomly selected to overcome the associated species effect. This was achieved by the unique randomization procedure used in generating feed combinations.

It was found upon inspection of means of R_5 that those with high standard deviations indicated animal effects rather than species combinations as the cause of the high standard deviations. MPTs were offered at 20-30% of dry matter intake. This was in line with forage supplement levels suggested by Devendra (1990) as those that poor resource farmers can realistically adapt.

Observations made in this trial indicated that the choice of trial length is important. An erratic behaviour on preference was observed on day 1. All the MPTs were tasted on the first day, and within the next 4 days preference rating was developed. An adaptation of at least one day should therefore be allowed in palatability studies. Observations based on linear regression, correlation coefficients, palatability ranking and cluster formation indicated that, if palatability is done to predict long-term intake of MPTs, at least 5 days are appropriate in palatability assessment for sheep. This gives a better accuracy of intake prediction. Periods less than 5 days lead to highly variable results while 5 to 12 days could be useful given the high r^2 values (r^2=0.93, 0.99, 0.97 for linear regression of A_5 on A_2, A_5 on A_3 and A_5 on A_4, respectively). This is in line with observations based on standard errors(SE) of means of adjusted palatability indices (SE=0.15, 0.13, 0.07, 0.10 for R_1, R_2, R_3 and R_4, respectively). Palatability trials of less than five days with sheep should be highly discouraged. This is similar to observations made by Ben Salem et al. (1994). The experimental model adopted for this study seems to be realistic and suitable for assessing palatability of browses (MPTs).

Clustering of the MPTs does not imply that species with low palatability are of less importance. Some species that are least preferred during times of abundance and variety could be relished during times of scarcity and severe feed shortages based on animal survival instinct. The choice of MPTs for pasture improvement should include species of different palatability as well as persistence so that the less palatable ones could provide fodder during periods of scarcity. In agroforestry systems, sowing of fodder trees of widely differing palatability, growth patterns, drought tolerance and persistence may be desirable to ensure year-round feed availability, thus ensuring increased animal productivity and optimization of land use.

Acknowledgements

We acknowledge the contribution of J. Mohammed and L. Makore at the ILRI Zwai seed multiplication site for their invaluable personnel and material support as well as M.L. Diedhiou for statistical work. The authors are grateful to A.M. Mih for critically reading the manuscript and GTZ for financing the fodder tree establishment.

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Chapter 3

Palatability of wilted and dried multipurpose tree species fed to sheep and goats

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Published in: Animal Feed Science and Technology (1997) 65:151-163.

Palatability of wilted and dried multipurpose tree species fed to sheep and goats

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Abstract

Palatability indices of dry and wilted 18 multipurpose tree species (MPTs) were determined using 12 wethers, 17.5 ±1.24 kg live weight (±SD) and 12 bucks, 20.5 ±1.46 kg live weight (±SD), blocked into two groups on live weight and age, housed in a roofed and half-walled shed with individual feeding pens. The 18 MPTs were randomly grouped into sets of six by form (dried and wilted) such that each animal received 3 of each form. Each animal received 0.5 kg teff straw (*Eragrostis tef*) in addition to 0.4 kg and 0.2 kg of the wilted and dry forms of the appropriate MPTs species respectively, daily at 08:00 h over a 12-day experimental period.

MPTs dry matter intake on day 1 (A_1), average intakes on days 2-4 (A_2), days 5-8 (A_3), days 9-12 (A_4) and days 2-12 (A_5) were compared. A significant ($P<0.0001$) decrease in intake with correlation coefficients of $r=0.92$ (A_1 and A_2,), $r=0.88$ (A_1 and A_5) and $r=0.85$ (A_1 and A_3) in sheep were observed. A similar trend was observed for palatability indices R_1, R_2 , R_3 ,and R_4. A close relationship was observed between R_2 and R_5 ($r=0.91$), R_3 and R_5 ($r=0.97$), R_4 and R_5 ($r= 0.94$). R_1 was poorly correlated to R_5 ($r=0.61$). The same trend was found in goats. Linear regressions of A_5 on A_1, A_5 on A_2, A_5 on A_3 and A_5 on A_4 (Adj. $r^2= 0.81, 0.95, 0.97, 0.94$ and $r^2= 0.64, 0.90, 0.97, 0.94$ in sheep and goats, respectively) showed that the best relationship existed between A_5 and A_3.The results of analysis of variance for palatability index R_5 showed that the palatability index significantly ($P<0.001$) depended on previous clustering and animal species. The cluster means for R_5 were 1.34, 1.02, 0.68 and 0.54 for clusters 1, 2, 3 and 4, respectively. However, the palatability indices for goats were more than double those for sheep (1.33 vs 0.48). There were no significant interaction effects for cluster, form and animal species. In this study the form of feed (wilted or dry) did not affect palatability index. *Acacia persiciflora, Leucaena leucocephala,* and *Chamaecytisus palmensis* were ranked high by both sheep and goats.

Key words: Palatability, multipurpose tree species, intake, sheep, goats, dry, wilted

Introduction

Trees and shrubs have potential value as sources of feed for domestic livestock and wildlife. They provide, in many cases, long-term stability or successful conservation of the production systems especially in environment of extreme oscillations (Sankary and Ranjhan, 1989). Most of the browse species are known to have high levels of antinutritional factors such as tannins. Tannins may reduce intake of forage legumes by decreasing palatability or negatively affecting digestion (Reed, 1995). The tannin astringency effect and chemical properties differ among plant species. Although drying provides a form that is easy to store, it could irreversibly "fix" tannins to other cell polymers (Swain, 1979). Nitis (1986) observed an improvement in acceptance of *Gliricidia sepium* after prolonged wilting or drying, while Palmer and Schlink (1992) reported a significant ($P<0.05$) difference between voluntary intake of fresh and wilted *Calliandra calothyrsus*. Marten (1970) and Arnold (1970) reported that palatability influences voluntary intake.

No universally-recognized definition of the term "palatability" exists, but the concept of palatability is of more importance than any specific definition. Palatability is a complex phenomenon determined by animal, plant and environmental variables. The palatability of a forage is determined by its ability to provide stimuli to the oropharyngeal senses of the animal, e.g. taste, odour and texture. Evidence exists that sheep, goats and cattle possess different degrees of sensitivity to palatability factors when a choice of feed is offered (Marten, 1978). Kaitho et al. (1996) demonstrated wide variation in the potential forage value and acceptability of 40 multipurpose tree species (MPTs) in sheep. Goats are known to be better browsers than either cattle or sheep. Therefore the objectives of this study were to validate the palatability method used by Kaitho et al. (1996) and to examine the effect of drying on palatability of multipurpose tree species leaves to sheep and goats.

Materials and methods

The study was carried out at the International Livestock Research Institute's (ILRI) seed multiplication site at Zwai in the Rift Valley of Ethiopia (8°00'N; 38°45'E). The site is situated at an altitude of 1650 m above sea level and receives an average annual rainfall of 600 mm. Sixteen MPTs were selected from a set of 40 MPTs whose relative palatability ranking was determined (Kaitho et al., 1996). Kaitho et al. (1996) used the mean palatability index (R_5) as classification variable in the clustering procedure to group the 40 MPTs into four clusters (Table 1) using Ward's minimum variance cluster analysis (SAS 1987). The number of species selected per cluster were 6, 3, 3 and 4 for clusters 1, 2, 3, and 4, respectively. Two other species (*Acacia nilotica* and *Erythrina*

brucei) were included in this study.

From a group of 15 sheep and 17 goats purchased at a local market, 12 animals of each species were selected based on age (according to dentition) and live-weight after a 21-day quarantine period. The twelve wethers, 17.5 ±1.24 kg live weight (±SD) and twelve bucks 20.5 ±1.46 kg live weight (±SD), were blocked into two groups on live weight and age and then housed in a roofed and half-walled shed with individual feeding pens. Each animal was provided with a feeding trough having seven separate compartments to accommodate test feeds. The animals underwent 10 days adaptation to confinement feeding. Data collection took 12 days which were divided into three periods of 3-4 days. The 18 MPTs (Table 1) were randomly grouped into sets of six by form (dried and wilted) such that each animal received 3 samples of each form as shown in Table 2. The MPTs were dried in a shed for 5 to 10 days, while forages were wilted during the period they were available to the animals. Fresh leaves previously stored in the cold room (4°C), were offered in the morning, and as ambient temperature (min 13.4 ± 1.80°C, max 28.4 ± 2.12°C) was high and the relative humidity was low (54.4 ±0.14%, 37.2±7.25% and 38.2±8.26% at 8.00h, 13.00h and 16.00h, respectively), the material wilted before weighing the refusal the next day.

Feeds and feeding

Each animal was fed grass hay, dried and wilted *Desmodium intortum*, wilted *Dolichos lablab* and *Newnotonia wightii* leaves ad-libitum, each placed in a separate feeding compartment, during the adaptation period of 10 days. During the data collection period, each animal was given 0.5 kg teff straw (*Eragrostis tef*) in addition to 0.4 kg and 0.2 kg of the wilted and dried forms of the appropriate MPTs respectively. Fresh MPT leaves were harvested and stored in a cold room for feeding the next day. Feeds were offered at 08:00 h daily. The order of placement of the test feed in the feed trough was randomized every day to avoid 'habit reflex'. Water was provided ad-libitum using a rubber bucket.

Measurements, calculations and statistical analysis

The feeds offered and refused were recorded for each animal daily and refusal samples kept separately on individual animal basis. Samples of daily feed offered were pooled over the experimental period by species and air-dried under shed for chemical analysis. Dry matter (DM), was assayed on the offered and refused feed while, ash and nitrogen (N) were assayed on the offered feed using the method of the Association of Official Analytical Chemists (1990). Neutral detergent fibre (NDF), acid detergent fibre (ADF)

Table 1: Identity, previous cluster group and chemical composition of MPTs offered to sheep and goats.

Fcode	Species	cluster	Form	DM	Ash	N	NDF	ADF	Pas
19	*Acacia nilotica* (7177)	-	dry	927	44	31	391	282	46
1	*Acacia nilotica*		wilted	434					
33	*Acacia persiciflora* (10560)	1	dry	927	92	28	525	390	29
15	*Acacia persiciflora*		wilted	473					
20	*Acacia polyacantha* (10587)	1	dry	931	87	45	498	300	101
2	*Acacia polyacantha*		wilted	387					
22	*Acacia saligna* (7178)	2	dry	928	117	24	447	302	73
4	*Acacia saligna*		wilted	326					
23	*Albizia schimpheriana* (10562)	4	dry	933	74	41	646	463	19
5	*Albizia schimpheriana*		wilted	407					
24	*Calliandra calothyrsus* (15143)	2	dry	927	110	36	505	389	54
6	*Calliandra calothyrsus*		wilted	396					
25	*Ceratonia siliqua* (6908)	4	dry	926	59	16	506	419	60
7	*Ceratonia siliqua*		wilted	435					
26	*Chamaecytisus palmensis* (15373)	1	dry	930	53	34	449	273	6
8	*Chamaecytisus palmensis*		wilted	298					
27	*Entada abyssinica* (10600)	3	dry	911	96	31	519	369	27
9	*Entada abyssinica*		wilted	352					
29	*Erthrina brucei* (10625)	-	dry	936	120	40	533	389	4
11	*Erthrina brucei*		wilted	272					
28	*Erythrina abyssinica* (10640)	4	dry	940	110	36	600	417	7
10	*Erythrina abyssinica*		wilted	291					
21	*Erythrina burana* (12159)	4	dry	953	127	30	554	398	69
3	*Erythrina burana*		wilted	259					
30	*Gliricidia sepium* (7069)	3	dry	915	128	39	450	240	56
12	*Gliricidia sepium*		wilted	269					
31	*Leucaena leucocephala* (14977)	1	dry	925	171	25	414	274	30
13	*Leucaena leucocephala*		wilted	310					
32	*Leucaena pallida* (14191)	1	dry	934	105	31	377	226	46
14	*Leucaena pallida*		wilted	354					
34	*Samanea saman* (14884)	3	dry	939	65	35	446	344	13
16	*Samanea saman*		wilted	343					
35	*Sesbania goetzei* (15007)	2	dry	924	96	40	430	297	103
17	*Sesbania goetzei*		wilted	258					
36	*Sesbania sesban* (10865)	1	dry	928	108	49	287	214	20
18	*Sesbania sesban*		wilted	264					
37	*Eragrostis tef*	-	dry	949	75	6	787	439	ND

Fcode: multipurpose tree species code; The International Livestock Centre for Africa accesion numbers are given in parenthesis; DM: dry matter (g kg^{-1}); N:nitrogen (g kg^{-1} DM); NDF: neutral detergent fibre (g kg^{-1} DM); ADF: acid detergent fibre (g kg^{-1} DM); Pas: proanthocyanidins in absorbance (550 nm) g^{-1} NDF; ND: not determined.

Table 2. MPTs arragement in the combinations tested.

Animal No.	Pen no.	Block	Multipurpose tree codes#						
Sheep									
283	1	1	11	13	17	20	31	36	37
284	10	1	6	9	12	19	24	30	37
285	9	1	3	8	15	21	28	33	37
286	22	1	1	10	18	25	29	35	37
287	16	1	2	5	14	23	27	32	37
288	12	1	4	7	16	22	26	34	37
290	11	2	4	7	9	19	20	21	37
291	17	2	2	13	18	23	33	35	37
293	8	2	1	6	17	24	27	28	37
294	20	2	8	10	16	26	36	30	37
296	24	2	5	11	15	22	29	32	37
297	5	2	3	12	14	25	31	34	37
Goats									
298	6	1	11	13	17	20	31	36	37
299	14	1	6	9	12	19	24	30	37
300	19	1	3	8	15	21	28	33	37
301	13	1	1	10	18	25	29	35	37
303	3	1	2	5	14	23	27	32	37
305	23	1	4	7	16	22	26	34	37
307	7	2	4	7	9	19	20	21	37
308	4	2	2	13	18	23	33	35	37
309	18	2	1	6	17	24	27	28	37
310	15	2	8	10	16	26	30	36	37
312	21	2	5	11	15	22	29	32	37
313	2	2	3	12	14	25	31	34	37

decode by using Table 1.

and lignin were analyzed using the method described by Van Soest and Robertson (1985). Proanthocyanidins were assayed using the method of Reed et al. (1982).

The following variables were determined following the procedure described by Salem et al.

(1994) and Kaitho et al. (1996):

T_1 : teff straw intake on day 1;

T_2, T_3, T_4, T_5 : average teff straw intake on days 2-4, 5-8, 9-12 and 2-12, respectively;

A_1 : MPTs intake on day 1;

A_2, A_3, A_4, A_5 : average MPTs intake on days 2-4, 5-8, 9-12 and 2-12, respectively;

TD_1 : quantity of teff straw offered on day 1;

TD_2, TD_3, TD_4, TD_5 : average quantity of teff straw offered on days 2-4, 5-8, 9-12 and 2-12, respectively;

D_1 : quantity of MPTs offered on day 1;

D_2, D_3, D_4, D_5 : average quantity of MPTs offered on days 2-4, 5-8, 9-12 and 2-12, respectively;

Relative palatability indices (R) which described palatability of individual MPTs in relation to teff straw were calculated as:

$R_1 = (A_1/D_1)/(T_1/TD_1)$

$R_2 = (A_2/D_2)/(T_2/TD_2)$

$R_3 = (A_3/D_3)/(T_3/TD_3)$

$R_4 = (A_4/D_4)/(T_4/TD_4)$

$R_5 = (A_5/D_5)/(T_5/TD_5)$

The palatability index data were subjected to GLM procedure for analysis of variance and correlation and regression analyses of dry matter intake (A_i) on palatability indices (R_i) were performed using procedures in SAS (1987).

Results

The chemical composition of materials offered to sheep and goats is shown in Table 1. The nitrogen content varied from 16 g kg^{-1} DM (*Ceratonia siliqua*) to 49 g kg^{-1} DM, (*Sesbania sesban*). High levels of N were observed in *Acacia polyacantha* (45 g kg^{-1} DM), *Albizia schimpheriana* (41 g kg^{-1} DM), *S. goetzei* (40 g kg^{-1} DM), *Gliricidia sepium* (39 g kg^{-1} DM) and *Calliandra calothyrsus* (36 g kg^{-1} DM). *Leucaena leucocephala* had a low N content (25 g kg^{-1} DM) relative to the above species but a higher ash content (171 g kg^{-1} DM) than expected. This was attributed to defoliation by psyllid (*Heteropsylla cubana*) before the trial. High levels of ash were also observed in *G. sepium* (128 g kg^{-1} DM), *E. burana* (127 g kg^{-1} DM) and *A. saligna* (117 g kg^{-1} DM). The NDF contents of the MPTs differed appreciably varying from 287 g kg^{-1} DM (*S. sesban*) to 646 g kg^{-1} DM (*A. schimpheriana*) and ADF varied from 214 g kg^{-1} DM (*S. sesban*) to 463 g kg^{-1} DM (*A. schimpheriana*). All the MPTs contained detectable levels of proanthocyanidins (Table 1). Low levels were observed in *Chamaecytisus palmensis*, *Erythrina abyssinica*, *S. saman*, *A. schimpheriana* and *S. sesban*. However, *S. saman* and *A. schimpheriana* had strong characteristic odours which may influence their palatability.

An increasing trend in daily intake in both sheep and goats of *dry S. sesban, S. saman, L. leucocephala, Entada abyssinica, C. palmensis, A. persiciflora, A. nilotica* and *wilted A. nilotica* were observed from day 1 (Table 3 and 4). The reverse was true for dry *A. saligna, A. schimpheriana, S. saman,* wilted *S. goetzei* and wilted *A. schimpheriana* in sheep and wilted *A. schimpheriana,* wilted and dried *E. brucei* in goats. The sheep did not eat wilted *A. polyacantha, A. saligna, C. siliqua, Entada abyssinica* and *S. saman* on the first day. Surprisingly, goats showed a remarkable adaptation to both wilted and dried *S. saman.* The palatability indices and DM intake

trends were the same.

There was a decrease in intake with correlation coefficients of r=0.92 (A_1 and A_2,), r=0.88 (A_1 and A_5) and r=0.85 (A_1 and A_3) in sheep (Table 5). A similar trend was observed for palatability indices R_1, R_2 , R_3 ,and R_4. A close relationship was observed between R_2 and R_5 (r=0.91), R_3 and R_5 (r=0.97), R_4 and R_5 (r= 0.94). R_1 was poorly correlated to R_5 (r=0.61). The same trend was found in goats (Table 5). Linear regressions of A_5 on A_1, A_5 on A_2, A_5 on A_3 and A_5 on A_4 (Adj. r^2= 0.81, 0.95, 0.97, 0.94 and Adj. r^2= 0.64, 0.90, 0.97, 0.94 in sheep and goats, respectively) showed that the best relationship existed between A_5 and A_3 (Table 6).The correlation between sheep (S) and goat (G) palatability indices (R_5) was positive and significant (r^2 =0.46, P<0.005). The regression equation for this relationship was:

S = 0.10 (0.167) + 0.33 (0.107)G (RSD=0.44, Adj-R^2 =0.19 n=36).

To further elucidate the variability in palatability, form (wilted and dry), animal species (sheep and goats) and previous palatability cluster of these MPTs were studied. The results of analysis of variance for palatability index R_5 (Table 7) showed that the palatability index significantly (P<0.001) depended on previous clustering and animal species. The means of previous cluster groups (Kaitho et al., 1996) in this trial were 1.34, 1.02, 0.68 and 0.54 for clusters 1, 2, 3 and 4, respectively (sheep and goats). The trend was the same as the means of the groups within which these MPTs were selected. However, the palatability indices for goats were more than double those for sheep (1.33 vs 0.48). There was no significant interaction effect. The form of feed (wilted or dry) did not affect palatability index.

Palatability indices (R_5) means (wilted and dry form) were used in ranking the MPTs (Table 8). Sheep preferred, in a decreasing order, *A. persiciflora, L. leucocephala,* and A. nilotica to *E. tef.* The remaining species were less palatable to sheep as compared to *E. tef.* Goats gave a different order of preference, *A. nilotica* being the most palatable, followed by *A. persiciflora* and *L. leucocephala.* Goats had high preference for *A. saligna* and low preference for *G. sepium*, conversely to sheep. *Ceratonia siliqua* was ranked lowest by both animal species.

Discussion

Martz et al. (1967) acknowledged that in theory the chemical composition of forages should influence their palatability, and Heady (1964) stated that, presumably, chemical composition is the most important palatability factor. However, Irvins (1955) could not establish a correlation between the relative palatability and chemical composition of forage and its preference. Similarly, we observed (Kaitho et al., 1997) poor

Table 3. Dry matter (DM) intake and palatability indices of dry[$] and wilted MPTs for sheep

species	Intake (g DM day^{-1})					Palatability indices				
	A_1	A_2	A_3	A_4	A_5	R_1	R_2	R_3	R_4	R_5
Acacianilotica$	37	51	68	101	75	0.25	0.37	0.51	0.85	0.60
Acacia nilotica	145	140	164	169	159	1.12	1.19	1.49	1.55	1.43
Acacia persiciflora$	97	126	147	163	147	0.77	1.11	1.23	1.32	1.23
Acacia persiciflora	187	181	181	186	183	1.62	1.44	1.57	1.65	1.56
Acacia polyacantha$	30	8	28	84	43	0.25	0.08	0.23	0.69	0.35
Acacia polyacantha	0	11	2	21	11	0.00	0.12	0.01	0.18	0.10
Acacia saligna$	52	7	20	19	16	0.64	0.05	0.12	0.18	0.13
Acacia saligna	0	5	4	15	8	0.00	0.04	0.04	0.13	0.07
Albizia schimpheriana $	49	28	10	16	17	0.59	0.22	0.07	0.11	0.13
Albizia schimpheriana	26	2	7	9	6	0.37	0.01	0.05	0.15	0.08
Calliandra calothyrsus$	59	84	113	100	100	0.42	0.62	1.16	1.09	0.99
Calliandra calothyrsus	35	13	0	24	12	0.30	0.11	0.00	0.29	0.14
Ceratonia siliqua$	5	6	9	9	8	0.04	0.06	0.07	0.08	0.07
Ceratonia siliqua	0	5	1	0	2	0.00	0.03	0.01	0.00	0.01
Chamaecytisus palmensis$	94	98	98	174	126	0.57	0.60	0.58	1.26	0.83
Chamaecytisus palmensis	101	60	89	97	84	1.27	0.75	1.10	1.36	1.10
Entada abyssinica$	15	51	72	83	70	0.15	0.41	0.71	0.90	0.70
Entada abyssinica	0	18	16	8	14	0.00	0.17	0.19	0.11	0.15
Erthrina brucei$	14	18	32	26	26	0.10	0.15	0.24	0.31	0.24
Erthrina brucei	50	1	4	9	5	1.10	0.03	0.05	0.24	0.11
Erythrina abyssinica$	69	60	71	71	68	0.53	0.47	0.68	0.73	0.64
Erythrina abyssinica	1	1	5	1	2	0.02	0.01	0.05	0.01	0.02
Erythrina burana$	12	19	25	17	20	0.09	0.14	0.19	0.14	0.16
Erythrina burana	82	57	72	63	64	1.24	0.99	1.21	1.26	1.17
Gliricidia sepium$	14	18	53	77	52	0.09	0.13	0.55	0.82	0.53
Gliricidia sepium	44	30	52	36	40	0.61	0.55	0.85	0.63	0.69
Leucaena leucocephala$	112	133	154	165	152	1.15	1.62	1.88	1.85	1.80
Leucaena leucocephala	13	46	26	84	52	0.22	0.95	0.48	1.22	0.88
Leucaena pallida$	29	29	8	36	24	0.36	0.19	0.06	0.50	0.25
Leucaena pallida	62	82	65	105	84	0.71	0.97	0.83	1.32	1.04
Samanea saman$	29	27	22	7	18	0.22	0.18	0.19	0.06	0.14
Samanea saman	0	7	11	27	16	0.00	0.05	0.10	0.35	0.18
Sesbania goetzei$	145	101	95	173	125	1.09	0.84	0.69	1.16	0.90
Sesbania goetzei	56	14	18	10	14	1.04	0.33	0.35	0.18	0.28
Sesbania sesban$	76	61	101	110	93	0.57	0.42	0.70	1.04	0.75
Sesbania sesban	18	35	32	38	35	0.22	0.53	0.40	0.42	0.44
Eragrostis tef$	319	328	328	305	319	1.00	1.00	1.00	1.00	1.00

$R_i = (A_i/D_i)/(T_i/TD_i)$; A_i : MPTs intake; D_i : MPTs offered; T_i: teff straw intake; TD_i : teff straw offered; $_i$: 1 (day 1), 2 (day 2-4), 3 (day 5-8), 4 (day 9-12) and 5 (day 2-12); [$] : dry

relationships between palatability and chemical constituents. The MPTs had medium to high content of nitrogen (24-49 g kg^{-1} DM) except *C. siliqua* (16 g kg^{-1} DM), making them a valuable source of protein for livestock. Variations in NDF and ADF are similar to what Topps (1992) observed in a number of MPTs species.

Table 4. Dry matter (DM) intake and palatability indices of dry[$] and wilted MPTs for goats.

species	Intake (g DM day^{-1})					palatability indices				
	A_1	A_2	A_3	A_4	A_5	R_1	R_2	R_3	R_4	R_5
Acacianilotica$	92	120	159	155	147	0.81	1.16	1.75	1.96	1.66
Acacia nilotica	152	164	171	170	169	2.12	3.60	2.89	2.91	3.09
Acacia persiciflora$	145	160	164	175	167	2.25	2.44	1.82	2.35	2.18
Acacia persiciflora	186	184	173	182	179	3.64	2.20	1.79	2.39	2.12
Acacia polyacantha$	60	70	110	104	97	0.54	0.96	1.47	1.49	1.34
Acacia polyacantha	41	30	12	41	27	0.68	0.54	0.18	0.95	0.56
Acacia saligna$	125	133	181	172	165	1.86	1.38	2.10	2.49	2.04
Acacia saligna	79	71	105	127	104	1.01	1.13	1.91	2.60	1.95
Albizia schimpheriana$	29	101	62	63	73	0.31	2.04	0.80	1.03	1.22
Albizia schimpheriana	74	6	3	13	7	1.60	0.14	0.05	0.30	0.17
Calliandra calothyrsus$	81	84	83	105	92	0.66	0.69	0.74	1.11	0.86
Calliandra calothyrsus	144	71	117	111	102	1.89	1.16	1.47	1.46	1.38
Ceratonia siliqua$	9	8	28	29	23	0.10	0.14	0.50	0.48	0.39
Ceratonia siliqua	14	6	5	13	8	0.15	0.08	0.07	0.18	0.11
Chamaecytisus palmensis$	95	102	154	181	150	0.83	1.12	1.67	2.53	1.83
Chamaecytisus palmensis	114	117	102	104	107	2.15	2.30	1.50	2.07	1.93
Entada abyssinica$	85	110	117	109	112	1.30	2.03	1.60	1.55	1.70
Entada abyssinica	32	32	88	81	70	0.27	0.29	1.05	1.14	0.87
Erthrina brucei$	112	73	65	64	67	2.04	1.46	1.06	1.16	1.21
Erthrina brucei	95	39	47	38	42	2.68	1.05	0.91	0.80	0.91
Erythrina abyssinica$	56	71	62	48	59	0.88	1.17	0.73	0.58	0.79
Erythrina abyssinica	65	73	78	70	73	0.91	1.85	1.53	1.80	1.72
Erythrina burana$	89	77	123	108	105	0.88	0.95	1.48	1.52	1.35
Erythrina burana	42	38	46	29	37	0.87	0.63	0.72	0.48	0.61
Gliricidia sepium$	8	25	32	18	25	0.06	0.20	0.26	0.20	0.22
Gliricidia sepium	44	58	63	53	58	0.78	0.90	0.87	0.79	0.85
Leucaena leucocephala$	148	160	158	169	163	1.44	1.95	1.53	1.66	1.69
Leucaena leucocephala	108	118	109	120	116	1.93	2.81	1.91	2.41	2.34
Leucaena pallida$	66	106	168	165	150	0.92	1.56	1.98	2.41	2.02
Leucaena pallida	136	125	121	136	128	1.81	2.19	1.57	2.02	1.90
Samanea saman$	4	40	52	65	53	0.04	0.38	0.64	0.81	0.63
Samanea saman	0	62	75	105	82	0.00	0.93	1.23	2.06	1.45
Sesbania goetzei$	85	76	104	141	110	1.20	1.70	1.63	2.34	1.91
Sesbania goetzei	75	69	62	56	62	1.74	2.36	1.37	1.21	1.58
Sesbania sesban$	108	150	107	148	134	0.84	1.99	1.15	1.98	1.68
Sesbania sesban	101	65	78	72	72	2.28	2.35	2.13	2.04	2.16
Eragrostis tef$	246	223	241	216	227	1.00	1.00	1.00	1.00	1.00

$R_i = (A_i/D_i)/(T_i/TD_i)$; A_i : MPTs intake; D_i : MPTs offered; T_i: teff straw intake; TD_i : teff straw offered; $_i$: 1 (day 1), 2 (day 2-4), 3 (day 5-8), 4 (day 9-12) and 5 (day 2-12).[$] : dry

Results from studies examining the effect of palatability on the long term intake of forages by ruminants are equivocal (Marten, 1970; Greenhalgh and Reid, 1971; Minson and Bray, 1986; Weston and Davis, 1986; Burns et al. 1987; Doyle, 1988). In some studies no relationship was observed between preference for a forage and intake (Minson and Bray, 1986; Burns et al. 1987), whereas in others, palatability was

Table 5. Coefficients of determination (Adjusted r^2) between intake (A_i) and palatability indices (R_i) of MPTs.

Parameters	A_1	A_2	A_3	A_4	A_5	R_1	R_2	R_3	R_4	R_5
Sheep										
A_1	1.00	0.92_a	0.88_a	0.85_a	0.90_a	0.66_a	0.61_a	0.51_a	0.40_a	0.52_a
A_2		1.00	0.97_a	0.91_a	0.98_a	0.53_a	0.68_a	0.59_a	0.46_a	0.60_a
A_3			1.00	0.93_a	0.99_a	0.52_a	0.67_a	0.68_a	0.54_a	0.67_a
A_4				1.00	0.97_a	0.49_a	0.66_a	0.64_a	0.66_a	0.69_a
A_5					1.00	0.53_a	0.68_a	0.66_a	0.57_a	0.67_a
R_1						1.00	0.67_a	0.59_a	0.49_a	0.61_a
R_2							1.00	0.86_a	0.76_a	0.91_a
R_3								1.00	0.85_a	0.97_a
R_4									1.00	0.94_a
R_5										1.00
Goats										
A_1	1.00	0.82_a	0.78_a	0.75_a	0.81_a	0.44_a	0.27_c	0.26_c	0.18	0.25_c
A_2		1.00	0.90_a	0.86_a	0.95_a	0.23_c	0.47_a	0.44_a	0.31_b	0.44_a
A_3			1.00	0.94_a	0.98_a	0.20	0.32_b	0.49_a	0.38_a	0.44_a
A_4				1.00	0.97_a	0.19	0.33_b	0.49_a	0.52_a	0.49_a
A_5					1.00	0.21	0.37_a	0.49_a	0.43_a	0.47_a
R_1						1.00	0.45_a	0.38_a	0.36_a	0.44_a
R_2							1.00	0.79_a	0.65_a	0.88_a
R_3								1.00	0.82_a	0.95_a
R_4									1.00	0.91_a
R_5										1.00

subscripts a, b, c : level of significance less than 0.001, 0.01 and 0.05 probability, respectively;
$R_i = (A_i/D_i)/(T_i/TD_i)$; A_i: MPTs intake; D_i: MPTs offered; T_i: teff intake; TD_i : teff offered; $_i$: 1 (day 1), 2 (day 2-4), 3 (day 5-8), 4 (day 9-12) and 5 (day 2-12).

assumed to be responsible for observed differences in intake (Greenhalgh and Reid, 1971; Weston and Davis, 1986; Doyle, 1988). In this study, MPTs with good nutritive value such as *L. leucocephala*, *C. palmensis* and *A. persiciflora* had consistently high intake and palatability irrespective of the form offered to both sheep and goats and, therefore, are in line with the assertions made by Marten (1970) and Arnold (1970) that palatability influences voluntary intake.

Ceratonia siliqua was consistently unpalatable irrespective of form and animal species. The reason for its low palatability has not been established, while *A. schimpheriana*, *S. saman* and *A. polyacantha* have strong odours which may have affected palatability adversely. Drying of these MPTs, however, did reduce these odours, leading to an improvement in palatability. Animals showed adaptation to the odours with time.

Table 6. Linear regression of MPTs dry matter intake A_5 (Y) on A_1, A_2 A_3 and A_4.

Y	=	A	+	B	X	RMSE[a]	r^2	Prob. [b]
Goats								
A_5	=	39.741 (0.692)	+	7.532 (0.056)	A_1	43.383	0.6441	***
A_5	=	20.713 (0.883)	+	4.274 (0.033)	A_2	23.533	0.8953	***
A_5	=	4.961 (0.930)	+	2.660 (0.019)	A_3	13.500	0.9655	***
A_5	=	-2.168 (0.989)	+	3.743 (0.028)	A_4	17.969	0.9389	***
Sheep								
A_5	=	15.192 (0.886)	+	6.612 (0.046)	A_1	47.762	0.8136	***
A_5	=	11.673 (0.945)	+	3.341 (0.024)	A_2	24.415	0.9513	***
A_5	=	6.729 (0.939)	+	2.327 (0.016)	A_3	16.713	0.9772	***
A_5	=	-5.171 (0.987)	+	4.017 (0.028)	A_4	27.108	0.9400	***

[a] Root mean square error; [b] ***: P<0.0001; A_1 : MPTs intake day 1; A_2: average MPTs intake on days 2-4; A_3 : average MPTs intake on days 5-8; A_4 : average MPTs intake on days 9-12; A_5 : average MPTs intake on days 2-12;

Table 7. Analysis of variance of relative palatability index R_5.

Source	df	Type III SS	Mean squares	Probability
Cluster	3	18.09	6.03	0.0001
Form	1	0.06	0.06	0.6969
Species	1	22.53	22.53	0.0001
Cluster*Form	3	0.82	0.27	0.5380
Cluster*Species	3	2.43	0.81	0.0957
Form*Species	1	0.26	0.26	0.4084
Cluster*Form*Species	3	0.83	0.28	0.5298

Species: animal species; form: dry and wilted; cluster: previous cluster grouping.

Table 8. MPTs mean[$] palatability indices($R_5$) and relative ranking by sheep and goats

Sheep			Goats		
species	R_5	rank	species	R_5	rank
Acacia persiciflora	1.40	1	*Acacia nilotica*	2.38	1
Leucaena leucocephala	1.34	2	*Acacia persiciflora*	2.15	2
Acacia nilotica	1.02	3	*Leucaena leucocephala*	2.02	3
Eragrostis tef	1.00	4	*Acacia saligna*	2.00	4
Chamaecytisus palmensis	0.97	5	*Leucaena pallida*	1.96	5
Erythrina burana	0.67	6	*Sesbania sesban*	1.92	6
Leucaena pallida	0.65	7	*Chamaecytisus palmensis*	1.88	7
Gliricidia sepium	0.61	8	*Sesbania goetzei*	1.75	8
Sesbania sesban	0.60	9	*Entada abyssinica*	1.29	9
Sesbania goetzei	0.59	10	*Erythrina abyssinica*	1.26	10
Calliandra calothyrsus	0.57	11	*Calliandra calothyrsus*	1.12	11
Entada abyssinica	0.43	12	*Erthrina brucei*	1.06	12
Erythrina abyssinica	0.33	13	*Samanea saman*	1.04	13
Acacia polyacantha	0.23	14	*Eragrostis tef*	1.00	14
Erthrina brucei	0.18	15	*Erythrina burana*	0.98	15
Samanea saman	0.16	16	*Acacia polyacantha*	0.95	16
Albizia schimpheriana	0.11	17	*Albizia schimpheriana*	0.70	17
Acacia saligna	0.10	18	*Gliricidia sepium*	0.54	18
Ceratonia siliqua	0.04	19	*Ceratonia siliqua*	0.25	19

$ mean palatability indices (wilted and dry form)

Observations made in this trial indicate that both sheep and goats adapted to MPTs over time. Palatability indices derived from first day were poorly correlated to indices on subsequent days. This confirmed our earlier assertion (Kaitho et al., 1996) that preference on first day is erratic and preference rating is developed within the first 4 days. High correlations between A_5 and A_3 (r^2=0.97) indicate that the period of 5 to 8 days is ideal, which concurs with previous observations (Salem et al., 1994; Kaitho et al., 1996).

Among numerous plant factors that influence palatability to animals are species, intraspecific variation, chemical composition, morphology or physical traits, succulence or maturation, availability in non-controlled situations and form of forage controlled by mechanization (Marten, 1978). However, in this study, the form (dry or wilted) did not affect the palatability indices. *Acacia nilotica* and *Acacia persiciflora* were more preferred wilted than dry by both sheep and goats while the reverse was observed for *A. polyacantha, A. saligna, A. schimpheriana* and *Entada abyssinica.* Correlation and regression analysis indicate a poor predictability of palatability of sheep using goat palatability indices.

Among domesticated livestock, goats are superb browsers, therefore for using

browse and forbs they have no peer (Ensminger et al., 1990). This may be due to the ability of goats to secrete proline-rich protein in saliva (Robbins et al., 1987) and the high affinity of proline-rich protein for tannins, which might result in reduced astringency. This could have been the case with *C. calothyrsus, A. saligna, A. polyacantha, L. pallida, and S. goetzei* but not with *S. sesban*. The former are known to be high in tannins and were more preferred by goats than sheep in both forms. On average, palatability indices from goats were more than two fold those of sheep. Therefore, goats should be more preferred than sheep when assessing palatability since goats are better browsers.

The sheep and goats exhibited different preferences but the difference were modest except for *A. saligna*. Neither the goats nor the sheep consumed *C. siliqua* or *A. schimpheriana* leading us to conclude that they have limited potential for use as animal feeds. The palatability method used in this study is suitable for evaluating palatability of large number of browses and other forages under stall feeding condition. As compared to other conventional palatability methods (oesophageal fistula technique, stomach content analysis and faecal analysis) it is easy, cheap, less labourious and convenient for screening a wide range of forages. Beside palatability indices, this method gives information on dry matter intake which is an advantage over cafeteria method. Short palatability trials should be highly discouraged because animals show adaptation to feeds with time. If palatability is done to predict long term intake a period of 5 to 8 days should be allowed.

Acknowledgements

We acknowledge the contribution of Mark van de Wouw , Jemal Mohammed and Lejisu Makore of the ILRI Zwai seed multiplication site. The authors are grateful to the GTZ for financing the fodder tree establishment.

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Chapter 4

Inter-relationships between palatability, rumen degradability, gas production and chemical composition of browses

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Submitted : Agroforestry Systems

Inter-relationship between palatability, rumen degradability, gas production and chemical composition in browses

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Abstract

The aim of this work was to assess whether degradability, gas production or chemical constituents could predict the palatability of browses. Forty browse species were used for this study. Crude protein (CP) content ranged from 79 to 307 g kg^{-1} DM. The neutral detergent fibre (NDF) and acid detergent fibre (ADF) ranged from 694 and 523 g kg^{-1} DM to 220 and 146 g kg^{-1} DM, respectively. The NDF-bound nitrogen and ADF-bound nitrogen were particularly high in *Calliandra calothyrsus, Acacia polyacantha, S. sesban, Acacia venosa* and *Acacia hockii*. The estimated true protein digestibility (DCP) varied from 931 to 498 g kg^{-1} CP, however most of the browses had protein that was more than 70% digestible. High levels of tannins were observed in *Acacia* spp (especially *A. dolichocephala, A. hockii, A. microbotrya* and *A. salicina*), *Flemingia macrophyla* and *Leucaena pallida*. The browse species differed ($P<0.05$) in potential DM degradability (PD), rate of degradation (c), solubility, effective degradability (ED) and 24-h degradability. High PD and ED were observed in *Sesbania* spp, *Moringa stenopetala, Indigofera arrecta, Chamaecytisus palmensis* and *Atriplex* spp. The browses differed ($P<0.05$) in asymptotic gas (AG) production (ml g^{-1} OM) but had similar ($P>0.05$) periods of incubation at which half of the gas was formed (h). Palatability and DM intake were negatively correlated ($P<0.05$) to NDF, ADF, and lignin, and were positively related ($P<0.01$) to NDFN. The PD and AG were negatively ($P<0.001$) related to NDF, ADF and lignin, and positively ($P<0.001$) related to true protein digestibility (DCP). Total phenolics (TP) and total soluble proanthocyanidins (TC) were negatively ($P<0.05$) related to PD, ED and AG, but positively ($P<0.001$) related to DCP. A positive correlation was observed between TC and NDF bound phenolics ($r=0.55$ $P<0.001$) and, TC and TP ($r=0.40$, $P<0.01$). Prediction equations were poor for DM intake and palatability, moderate for gas production and good for potential and effective degradabilities. The phenolic components were more related to dry matter degradation and gas production than to palatability and dry matter intake. Lignin was negatively correlated to potential degradability and gas production. NDFN and AG had positive contribution to both palatability and DM intake. It was concluded that chemical constituents such as N, NDF, NDFN, ADF and lignin are essential in describing the nutritive value of browses. Cluster groups developed using palatability as classifying variable are different than the ones formed by using chemical composition attributes, gas production parameters or dry matter degradation characteristics.

Key words: Browses, palatability, gas production, degradability, chemical composition

Introduction

A large number of shrub and tree (browse) species have been documented as useful livestock fodders. Along with their diversity in size, there is a range of agronomic characteristics which has enabled establishment and growth to occur in different agro-ecological zones. In these zones bounded by the humid and arid, their contribution is greatest in the semi-arid and arid areas. This importance as animal fodder arises from the harsh environment and the limitation that this imposes on both the quantity and quality of natural pastures. In areas of very low rainfall ($\leq$ 400 mm) the tender shoots and leaves are often the main source of feed. Under these circumstances, the value of these browses is considerable in meeting the nutrient requirements and sustaining populations of ruminant livestock. In recent years, this traditional use has been complemented by their exploitation in the wetter areas, in which the protein-rich nature of the browse harvested from shrub and tree legumes and the ability of many to fix nitrogen have been recognized.

Browse species of tropical origin are attributed with deleterious properties in livestock nutrition, either via direct toxicity or reduced palatability. However, considerable variation exists between species or even among members of a single species in their propensity to elicit adverse effects. A significant number of browses catalogued by Skerman et al. [1988] were associated with moderate to low palatability, particularly as regards young plants, with livestock requiring a period of adaptation prior to an improvement in consumption. Low palatability of browses have been associated with condensed tannin content [Skerman et al., 1988; Kaitho et al., 1997].

Many of these browse species are being assessed agronomically [Shelton, 1994] and for feed value [Woodward and Reed, 1989; Reed et al., 1990; Tanner et al., 1990]. In addition to animal response, both nylon bag degradation and gas production characteristics of these browses have been studied [Siaw et al., 1993; Nsahlai et al., 1994]. There is little information on the relationship between palatability, dry matter intake or digestibility of browse, and reports on the relationship between chemical composition and nutritive value in browse plants have not always been consistent [Wilson, 1977]. For quick assessment and initial screening of browses, it would be cheaper and faster if dry matter intake and palatability can be predicted from relatively simple methods like degradation characteristics, gas production or chemical composition. This study was therefore designed to assess whether degradability, gas production or chemical constituents could predict the palatability of browse species. Correlation, regression and cluster analysis were used to test the hypothesis that palatability could be predicted by chemical constituents, degradability or gas production. A less stringent procedure involving cluster analysis was used to asses whether the above criterion variables could place browses in the same groups as the palatability

index.

Materials and methods

The main part of this study was carried out at the International Livestock Research Institute (ILRI), Debre Zeit Research Station, Ethiopia. Gas production was carried out at Wageningen Agricultural University, Department of Animal Nutrition, Netherlands. Wilted edible portions (leaves, petioles and twigs) of forty browse species were sampled from feed on offer (dried under shade) during a trial carried out at ILRI seed multiplication site at Zwai, in which dry matter intake (DMI) and a palatability index (R) were determined [Kaitho et al., 1996].The palatability indices were determined using the formula:

$$R = (A/D)/(T/TD)$$

where (A/D) is the ratio of browse intake to quantity offered and (T/TD) was the ratio of teff straw intake to quantity offered.

Rumen Degradability

Thirty rumen-fistulated male Ethiopian highland sheep (25.1 kg; SD=1.15; average age of 20 months) with rumen fistula were used for the degradability studies. Each animal was fed Suluta hay (CP=6%, NDF=72.4%) *ad libitum* and supplemented with 150 g wheat bran (CP=16.6%, NDF=46.9%) daily. The trial comprised 15 days adaptation followed by sessions of incubation. Rumen degradability of each browse species was determined using the nylon bag technique [Mehrez and Ørskov, 1977] in three sheep selected at random. Air-dry leaves were milled (2.5 mm screen) and about 2.5 g was weighed in per nylon bag (14 cm x 8 cm, 41μm pore size) and incubated for 3, 6, 12, 24, 48, 72, 96 and 120 h. After incubation the bags were washed using a non-automatic washing machine (Tefal alternatic, Finland). The water was changed five times with each cycle lasting 5 minutes. The bags were dried in a forced draught oven at 60°C for 48 h, cooled in a desiccator and weighed. The disappearance of dry matter from nylon bag was fitted to Ørskov and McDonald [1979] exponential equation:

$$P = a + b(1 - e^{-ct})$$

where p is the DM disappearance at time t, 'a' the zero time intercept, 'b' the slowly degradable fraction and 'c' the rate of degradation. Potential degradability (PD) was estimated as (a+b), while effective degradability (ED) was calculated using the equation [Ørskov and McDonald, 1979]:

$$ED = a + \frac{bc}{(k+c)}$$

assuming an outflow rate (k) of 0.04 per hour.

Gas production

Cumulative gas production was measured according to the *in vitro* fermentation method of Theodorou et al. [1994] as modified by Williams et al. [1995]. This method allows the measurement of cumulative gas production using a pressure transducer under strictly anaerobic conditions to allow maximum efficiency of the cellulolytic bacteria. Air dried browse material were ground through a 1-mm screen and fermented in a 100 ml serum bottle (0.8 g sample), containing 80 ml of semi-defined medium (modified from Lowe et al. [1985], by omission of the coenzyme M solution). The (usually negative) pressure within the bottle was read at zero time and the difference calculated for the actual change in pressure for the next reading. The 5 ml of inoculum comprised rumen fluid from three sheep fed a constant diet of medium-quality hay prepared according to the method of Theodorou et al. [1994]. The amount of gas produced (G ml g^{-1} OM) at time t after incubation were fitted to the monophasic model developed by Groot et al. [1996]:

$$G = \sum_{i=1}^{n} \frac{A_i}{1 + \frac{B_i^{C_i}}{t^{C_i}}}$$

where G is amount of gas produced per g organic matter incubated, A_i is the asymptotic gas production (ml g^{-1} OM), B_i is the time after incubation at which half of the asymptotic amount of gas has been formed (h), C_i is a constant determining the sharpness of the switching characteristics of the profile and "i " denotes the number of phases in the profile (i=1, n). The curves were fitted using a nonlinear programme [Sherrod, 1995].

Chemical analysis

Ash and nitrogen (Kjehdal method) were analysed using the procedures described by the Association of Official Analytical Chemists [AOAC, 1990]. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were analysed using the method of Van Soest and Robertson [1985]. Nitrogen that is insoluble in neutral detergent (NDFN) and

acid detergent (ADFN) were assayed using the Kjedahl method. The true forage protein digestibility (DCP) was estimated from acid detergent insoluble crude protein (ADICP) because the concentration of ADICP when expressed as a proportion of total CP is highly correlated with the true digestibility of forage protein [Thomas et al., 1982] and can be used to estimate the true digestibility of forage crude protein [Weiss et al., 1983; Weiss et al., 1992] as: DCP=exp (-0.012 ADICP). The nitrogen solubility in phosphate buffer (Nsol) was determined by the procedure of Krishnamoorthy et al. [1983]. Total water-soluble phenolics (TP) were determined in the filtrate following water extraction. Tannins in the filtrate were transformed to a blue-coloured product by Folin-Denis reagent and sodium carbonate [Kaitho et al., 1993]. The intensity of the colour was measured at 760 nm. The content of total phenolics was calculated using a calibration line prepared using tannic acid (Sigma, T0125) as the standard compound (substrate). Colorimetric determination of condensed tannins (TC) was done according to the method of Porter et al. [1986]. Acetone-soluble polyphenolics (AP) in browses were determined by precipitation with trivalent ytterbium [Reed et al., 1985]. To determine the neutral-detergent insoluble proanthocyanidins (NDFP), 2 mg of NDF was heated at 95°C for one hour in n-butanol containing 5% concentrated HCl and the absorbance read at 550 nm [Reed at al., 1982].

Statistical analysis

Dry matter degradability and gas production parameters, were subjected to analysis of variance (ANOVA) using the General Linear Model procedure (GLM) available in SAS [1987]. Correlation analyses were used to establish the relationship between palatability indices, dry matter intake and chemical composition attributes. Multiple regression equations were established between palatability index, DM intake, DM degradability characteristics, gas production parameters and chemical composition attributes of browse species using the stepwise method. The variable entry criterion was set at 0.15 probability level of significance and elimination of certain early entry variables if they are made redundant by new variables allowed in the equation. Cluster analysis (FASTCLUS procedure) was carried out to identify browse species groups with similar characteristics, using palatability cluster group means as seed. The criterion variables used for clustering were chemical constituents, gas production parameters and DM degradation characteristics. To avoid the problem of autocorrelation, groups of reclassification variables were selected such that the correlation coefficients among variables were less than 0.5. The groups of re-classification variables were selected based on the result of stepwise discriminant analysis.

Results

Data on the chemical composition of the air-dried browse species are shown in Table 1. Crude protein (CP) content ranged from 79 g kg^{-1} DM in *Casuarina glauca* to 307 g kg^{-1} DM in *Sesbania sesban* var. bicolor. CP was particularly high in *Sesbania* species, *Gliricidia sepium, Albizia schimperiana* and *Acacia polyacantha*. High nitrogen solubility in phosphate buffer was found in *Atriplex rhagodiodes, Moringa stenopetala, Atriplex numularia, S. sesban* var. bicolor and *Sesbania sesban*, while lower levels were found in many of the *Acacia* species. The NDF ranged from 694 g kg^{-1} DM in *Casuarina glauca* to 220 g kg^{-1} DM in *S. sesban* var. bicolor, whereas the NDFN and ADFN were particularly high in *Calliandra calothyrsus, Acacia polyacantha S. sesban, Acacia venosa* and *Acacia hockii*. The ADF content ranged from 523 g kg^{-1} DM in *C.* glauca to 146 g kg^{-1} DM in *S. sesban* var. bicolor. The estimated true protein digestibility varied from 931 g kg^{-1} CP in *S. sesban* to 498 g kg^{-1} CP in *Acacia dolichocephala*, however, most of the browses had protein that was more than 70% digestible. Different levels of tannins were detected using the various methods (AP, NDFP, TP and TC). High levels of tannins were observed in *Acacia* species especially *A. dolichocephala, A. hockii, A. microbotrya* and *A. salicina*. High levels were also observed in *Flemingia macrophyla* and *Leucaena pallida*.

Table 2 shows comparisons of DM degradability and gas production characteristics of the browses. The browse species differed ($P<0.05$) in potential DM degradability (PD), rate of degradation (c), solubility (W), effective degradability (ED) and 24-h degradability (D24). High PD and ED were observed in *Sesbania* species, *M. stenopetala, Indigofera arrecta, Chamaecytisus palmensis* and *Atriplex* species. The rate of DM degradation was fastest in *Atriplex halimus, G. sepium, Tamarindus indica, S. sesban* var. bicolor and *Erythrina bentipoeme*, and slowest for *Acacia melanoxylon, Ceratonia siliqua* and *Casuarina equisetifolia*. The browse species differed ($P<0.05$) significantly in asymptotic gas (AG) production (ml g^{-1} OM) and the switching characteristics of the gas production profiles but had similar ($P>0.05$) times after incubation at which half of the asymptotic gas has been formed (h). Browse species with high PD and ED such as *Sesbania* species, *Atriplex* species, *C. palmensis, I. arrecta* and *Leucaena leucocephala* had high volume of gas production. Browse species such as *Acacia microbotrya* and *A. schimperiana* with both poor DM intake and palatability also had low gas production volume.

Relationships between palatability indices, DM intake, DM degradability characteristics, gas production constants and chemical composition of the browses are given in Table 3 . Palatability and DM intake were negatively correlated ($P<0.05$) to NDF, ADF, and lignin, and positively related ($P<0.01$) to NDFN. The PD and AG were negatively ($P<0.001$) related to NDF, ADF and lignin, and positively ($P<0.001$) related

Table 1. Chemical composition (g/kg) of the browse species.

SPECIES	OM	CP	Nsol	NDF	NDFN	ADF	ADFN	DCP	Lignin	AP	NDFP	TP	TC
Acacia coriacea	894	126	337	573	16	417	13	720	220	97	41	25	22
Acacia dolichocephala	946	139	128	525	33	449	29	498	246	282	113	157	81
Acacia hockii	926	165	125	396	45	304	26	694	124	329	25	201	12
Acacia horrida	843	155	149	394	40	252	21	771	118	125	103	52	36
Acacia melanoxylon	946	144	91	595	26	479	20	603	292	93	53	91	35
Acacia microbotrya	943	153	191	412	32	282	20	754	169	290	18	140	22
Acacia persiciflora	908	177	253	525	31	388	21	703	202	116	29	72	19
Acacia polyacantha	913	279	258	498	48	297	26	815	133	89	101	196	14
Acacia salicina	831	143	221	463	27	287	21	730	141	175	110	74	39
Acacia saligna	883	149	176	447	29	297	18	760	146	160	73	52	45
Acacia sieberiana	892	207	254	526	32	354	20	779	212	205	85	25	20
Acacia venosa	918	216	179	491	43	366	30	681	175	294	23	59	21
Albizzia schimperiana	926	259	283	646	37	478	29	671	254	233	19	46	5
Atriplex halimus	705	132	373	401	26	211	9	893	145	134	7	6	3
Atriplex nummularia	656	175	424	379	37	171	19	874	103	342	7	0	2
Atriplex rhagodiodes	707	158	513	397	23	214	7	930	76	233	7	4	3
Calliandra calothrysus	890	223	143	505	51	440	31	631	190	392	54	88	14
Casuarina cunninghamiana	921	104	201	613	13	459	10	718	195	415	29	93	19
Casuarina equisetifolia	922	86	178	450	11	334	9	779	137	518	21	106	40
Casuarina glauca	949	79	238	694	10	523	9	639	208	403	49	59	26
Ceratonia siliqua	941	103	140	506	23	401	18	584	196	492	60	133	7
Chamaecytisus palmensis	947	209	216	449	37	255	12	894	81	241	6	34	1
Entada abyssinica	904	191	169	519	37	377	28	665	222	267	27	21	14
Enterolobium cyclocarpum	894	209	363	416	36	279	25	781	123	216	55	16	3
Erythrina burana	873	187	315	554	25	412	10	853	81	329	69	9	1
Erythrina abyssinica	890	226	275	600	28	429	11	855	110	144	7	17	2
Erythrina bentipoeme	884	211	333	560	30	398	10	874	87	82	5	11	2
Flemingia macrophylla	910	176	163	584	27	452	17	720	188	341	75	48	79
Gliricidia sepium	872	241	263	450	42	284	19	844	155	107	56	12	2
Indigofera arrecta	878	231	315	295	35	196	17	895	60	71	43	30	3
Leucaena leucocephala	828	153	229	414	35	262	21	763	144	134	30	21	12
Leucaena pallida	895	195	209	377	41	220	20	848	102	333	46	84	30
Leucaena pulverulenta	835	184	229	419	42	321	35	636	187	74	25	29	4
Moringa stenopetala	866	229	479	276	36	255	14	888	56	88	35	24	2
Samanea saman	935	217	290	446	23	344	14	846	168	104	13	65	11
Sesbania goetzei	904	248	263	430	28	285	25	810	152	57	103	22	20
Sesbania sesban	899	304	375	287	48	199	15	931	55	96	20	21	2
S. sesban var. bicolor	892	307	394	220	44	146	21	927	50	77	7	25	3
Tamarindus indica	927	139	141	484	22	324	11	821	121	287	85	14	8
Tipuana tipu	896	169	317	467	21	321	14	823	129	106	29	65	16

OM: organic matter (g kg^{-1} DM); CP: crude protein (g kg^{-1} DM); NSOL: nitrogen solubility (g kg^{-1} DM); NDF: neutral detergent fibre (g kg^{-1} DM); NDFN: neutral detergent fibre bound nitrogen (g kg^{-1} NDF); ADF: acid detergent fibre (g kg^{-1} DM); ADFN: acid detergent fibre bound nitrogen (g kg^{-1} ADF); DCP: true CP digestibility (g kg^{-1} CP); AP: acetone-soluble phenolics (g kg^{-1} DM); NDFP: NDF bound proanthocyanidins (550 nm OD per g NDF); TP: total phenolics (g kg^{-1} DM);TC: Total soluble proanthocyanidins (g kg^{-1} DM).

Table 2. Variation in dry matter degradation and gas production characteristics of browse species.

SPECIES	R[$]	DMI[$]	Cluster$	W	PD	C	D24	ED	AG	BG	CG
Acacia coriacea	0.15	14.8	4	336	490	4.4	427	416	104.3	1.53	21.41
Acacia dolichocephala	0.43	46.1	3	230	410	3.2	320	292	52.4	0.98	77.29
Acacia hockii	1.09	113.6	1	196	556	2.7	368	302	81.7	1.49	36.79
Acacia horrida	0.96	128.3	1	316	673	2.1	413	435	78.9	1.57	37.69
Acacia melanoxylon	1.12	111.4	1	274	503	0.7	345	309	66.0	1.21	34.55
Acacia microbotrya	0.20	20.5	4	261	666	2.2	448	405	41.2	1.56	20.58
Acacia persiciflora	1.24	133.5	1	250	524	3.0	391	353	94.4	1.55	23.49
Acacia polyacantha	1.09	115.3	1	164	588	4.4	487	383	47.0	0.95	34.15
Acacia salicina	0.17	18.7	4	371	540	1.8	420	420	87.8	1.73	31.66
Acacia saligna	0.68	63.9	2	380	663	2.8	494	498	122.3	1.31	24.00
Acacia sieberiana	0.95	96.6	2	297	620	4.4	511	467	95.5	1.93	18.97
Acacia venosa	1.28	121.7	1	277	633	7.3	474	409	78.1	1.59	32.18
Albizzia schimperiana	0.23	19.9	4	231	471	1.8	325	290	45.0	1.32	19.87
Atriplex halimus	0.92	58.2	2	389	797	9.9	744	675	138.8	1.85	19.31
Atriplex nummularia	1.09	66.0	1	392	813	7.4	728	665	125.0	1.95	22.37
Atriplex rhagodiodes	0.80	45.7	2	424	832	6.4	725	671	103.2	2.12	22.43
Calliandra calothrysus	0.95	111.9	2	271	687	1.5	353	356	75.7	1.22	46.39
Casuarina cunninghamiana	0.39	58.4	3	246	674	1.1	296	278	70.9	1.44	29.43
Casuarina equisetifolia	0.71	87.3	2	204	750	0.4	375	248	94.6	1.03	56.41
Casuarina glauca	0.12	17.0	4	200	357	1.8	288	249	76.1	1.24	30.80
Ceratonia siliqua	0.11	13.4	4	236	229	0.5	338	217	99.0	1.26	48.74
Chamaecytisus palmensis	1.20	132.0	1	471	874	4.8	728	686	124.9	2.10	21.09
Entada abyssinica	0.64	60.6	3	243	420	2.7	328	306	85.2	1.57	26.79
Enterolobium cyclocarpum	0.48	47.2	3	370	655	3.4	554	488	71.9	1.43	36.30
Erythrina burana	0.10	5.9	4	204	715	6.6	606	511	113.0	2.03	20.78
Erythrina abyssinica	0.22	14.2	4	105	654	7.5	570	462	87.7	2.06	23.35
Erythrina bentipoeme	0.89	57.5	2	205	689	8.0	615	524	97.3	2.09	20.51
Flemingia macrophylla	0.24	31.1	4	294	496	1.6	343	346	78.9	1.17	45.67
Gliricidia sepium	0.54	41.7	3	406	750	9.5	694	642	101.1	1.90	20.78
Indigofera arrecta	1.30	106.2	1	444	962	4.8	801	689	105.7	1.95	32.01
Leucaena leucocephala	0.96	126.9	1	376	680	3.5	537	508	118.8	1.42	23.40
Leucaena pallida	1.29	137.8	1	371	747	2.7	529	519	97.2	1.70	34.34
Leucaena pulverulenta	1.05	118.0	1	235	650	4.0	534	443	83.7	1.63	24.50
Moringa stenopetala	0.90	66.3	2	410	947	5.7	792	721	100.7	2.06	18.58
Samanea saman	0.43	44.2	3	271	588	6.3	520	448	76.9	1.72	26.53
Sesbania goetzei	0.78	48.7	2	318	832	7.4	731	651	97.9	1.75	20.03
Sesbania sesban	1.19	121.1	1	426	927	6.9	822	742	127.8	1.81	18.32
Sesbania sesban var. bicolor	1.46	100.4	1	429	916	8.1	831	754	130.5	1.81	17.58
Tamarindus indica	1.30	106.0	1	341	673	9.3	629	570	108.8	1.77	18.83
Tipuana tipu	1.19	145.1	1	367	717	5.7	618	564	118.1	1.61	19.13
SED (n=3)				64	139	2.6	131	117	19.0	0.27	10.16

R: palatability index; $: refer to Kaitho et al., (1996); DMI: dry matter intake (g day^{-1}); W: solubility (g kg^{-1} DM); PD: potential degradability (g kg^{-1} DM); c: rate of degradation (%/h); D24: 24-h degradability; ED: effective degradability (g kg^{-1} DM); AG: asymptotic gas production (ml g^{-1} OM); BG: time after incubation at which half of the asymptotic gas has been formed (h); CG: constant determining the sharpness of the switching characteristics of the profile.

Table 3. Correlation coefficients between palatability index (R), dry matter intake (DMI) and chemical composition attributes of multipurpose trees species.

	R	DMI	N	Nsol	DCP	NDF	NDFN	ADF	Lignin	PD	ED	D24	AG	BG	CG	AP	NDFP	TP	TC
R	1.00	0.90_a	0.37_d	0.09	0.34	-0.56_b	0.49_b	-0.55_b	-0.38_d	0.35_d	0.47_c	0.46_c	0.38_d	0.22	-0.20	-0.33_d	-0.18	-0.07	-0.24
DMI		1.00	0.23	-0.16	0.12	-0.40_c	0.46_c	-0.37_d	-0.20	0.14	0.20	0.18	0.22	-0.02	-0.03	-0.22	-0.08	0.12	-0.08
N			1.00	0.37_d	0.45_c	-0.40_c	0.71_a	-0.35_d	-0.39_d	0.40_c	0.51_b	0.55_b	0.06	0.33_d	-0.36_d	-0.53_b	-0.11	-0.22	-0.40_c
Nsol				1.00	0.70_a	-0.41_c	0.00	-0.49_b	-0.57_a	0.55_b	0.71_a	0.71_a	0.44_c	0.61_a	-0.54_b	-0.39_d	-0.42_c	-0.56_b	-0.54_b
DCP					1.00	-0.56_b	0.09	-0.70_a	-0.85_a	0.71_a	0.86_a	0.84_a	0.60_a	0.73_a	-0.61_a	-0.38_d	0.35_d	0.51_b	0.53_b
NDF						1.00	-0.47_c	0.92_a	0.70_a	-0.73_a	-0.72_a	-0.70_a	-0.47_c	-0.38_d	0.18	0.33_d	0.17	0.14	0.29
NDFN							1.00	-0.41_c	-0.24	0.26	0.24	0.26	-0.06	0.08	-0.03	-0.28	0.00	0.09	-0.21
ADF								1.00	0.74_a	-0.74_a	-0.78_a	-0.75_a	-0.55_b	-0.48_c	0.34_d	0.34_d	0.18	0.24	0.36_d
Lignin									1.00	-0.76_a	-0.78_a	-0.77_a	-0.57_a	-0.63_a	0.34_d	0.20	0.24	0.31_d	0.45_c
PD										1.00	0.84_a	0.84_a	0.64_a	0.62_a	-0.39_d	-0.28	-0.19	-0.39_d	-0.53_b
ED											1.00	0.99_a	0.67_a	0.74_a	-0.56_b	-0.49_b	-0.29	-0.57_a	-0.55_b
D24												1.00	0.66_a	0.75_a	-0.57_a	-0.55_b	-0.27	-0.57_a	-0.57_a
AG													1.00	0.56_b	-0.44_c	-0.20	-0.28	-0.59_a	-0.36_d
BG														1.00	-0.69_a	-0.37_d	-0.37_d	-0.67_a	-0.62_a
CG															1.00	0.51_b	0.40_c	0.60_a	0.67_a
AP																1.00	0.00	0.35_d	0.25
NDFP																	1.00	0.27	0.55_b
TP																		1.00	0.40_c
TC																			1.00

R: palatability index; DMI: dry matter intake; N: nitrogen; Nsol: nitrogen solubility; DCP: true CP digestibility (g kg^{-1}CP); NDF: neutral detergent fibre;NDFN: neutral detergent fibre bound nitrogen; ADF: acid detergent fibre; PD: potential degradability; ED: effective degradability; D24: 24-h degradability; AG: asymptotic gas production (ml g^{-1} OM); BG: time after incubation at which half of the asymptotic gas has been formed (h); CG: constant determining the sharpness of the switching characteristics of the profile; AP: acetone-soluble phenolics; NDFP: fibre bound proanthocyanidins; TP: total phenolics; TC: Total soluble proanthocyanidins; subscripts a, b, c , d: level of significance for 0.0001, 0.001, 0.01 and 0.05 probability, respectively.

to true protein digestibility (DCP). Total phenolics (TP) and total soluble proanthocyanidins (TC) were negatively ($P<0.05$) related to PD, ED, AG and Nsol, but positively ($P<0.001$) related to DCP. A positive correlation was observed between TC and NDFP ($r=0.55$ $P<0.001$) and, TC and TP ($r=0.40$, $P<0.01$).

The regression equations developed by stepwise method for predicting palatability, DM intake, DM degradability and gas production from chemical constituents are given in Table 4. Prediction equations were poor for DM intake and palatability, moderate for gas production and good for potential and effective degradabilities. Tannin content had a negative contribution to PD, ED and gas production. Lignin also made a negative contribution to PD and gas production. Gas production (AG) and NDF bound nitrogen had positive contribution to both palatability and DM intake.

Table 4. Relationships between palatability, DM intake, DM degradation characteristics, gas production constants or chemical properties of browses.

Dependent variable	Equation (n=40)	RSD	R^2
R	-0.57(0.28) + 0.21(0.05)NDFN +0.01(0.002)AG	0.33	0.44
DMI	-19.87(30.39) + 20.81(5.70)NDFN + 0.71(0.27)AG - 1.46(0.64)Nsol	35.92	0.37
PD	117.88(8.27) - 1.04(0.44)Lignin - 0.81(0.23)NDF - 2.89(1.18)TC -0.59(0.37)TP + 0.09(0.06)NDFP	10.47	0.74
ED	-34.68(9.24) + 69.97(12.45)DCP + 0.57(0.11)NDS - 0.69(0.22)TP -0.13(0.08)AP	5.74	0.87
AG	171.20(15.77) - 2.24(0.53)TP - 0.79(0.40)ADF - 1.19(0.51)CP -1.21(0.66)Lignin	15.80	0.61
PD	-7.35(11.46) + 0.34(0.11)AG + 22.33(8.16)BG	13.82	0.51
ED	-18.23(7.881) +24.65(5.610)BG + 0.23(0.077)AG	9.50	0.63

R: palatability index; DMI: dry matter intake; CP: crude protein; Nsol: nitrogen solubility; NDF: neutral detergent fibre; NDFN: neutral detergent fibre bound nitrogen; ADF: acid detergent fibre; PD: potential degradability; ED: effective degradability; DCP: true forage crude protein digestibility; AP: acetone-soluble phenolics; NDFP: fibre bound proanthocyanidins; TP: total phenolics; TC: Total soluble proanthocyanidins; NDS: neutral detergent soluble fraction; AG: asymptotic gas production; BG: time after incubation at which half of the asymptotic gas has been formed; SE given in parenthesis.

The chances of misclassifying species when chemical constituents, degradation characteristics or gas production parameters were used as re-classification variables instead of palatability index are shown in Table 5. Regardless of the re-classification variables used, the level of misclassification were high ranging from 33.3 to 88.9%. Misclassification was relatively higher in cluster 1 and 2 than clusters 3 and 4.

Discussion

The inability of tropical grasses to support a level of animal production comparable to temperate grasses has generally been ascribed to the lower nitrogen content and poorer digestibility of the former [Minson, 1982]. A potential legume forage material to be used to enhance the quality of poor quality roughages and crop residues should therefore have a high protein content to supply readily fermentable protein. There would be an added advantage if the legume contains other critical nutrients such as minerals, vitamins, lipids and other compounds which enhance the rumen ecosystem [Preston, 1986]. It appears from the present study that most of the browses have a great potential to enhance the nutritive value of low nitrogen pastures and poor quality crop residues because they contain satisfactory levels of protein (Table 1) and minerals (Bonsi et al., 1994; Aletor and Omodara, 1994). In addition to their perennial nature, these browses have high herbage yields and could be harvested and fed to livestock at any time of the year to increase the efficiency of utilization of the basal diets.

In this study, the browses had widely varying effective degradabilities (217-754 g kg^{-1} DM) and total gas productions (45-130.5 ml g^{-1} OM). Similar variation in gas production and DM degradabilities have been demonstrated previously [Siaw et al., 1993; Nsahlai et al., 1994; Nsahlai et al., 1995; Khazaal et al., 1995]. The data on degradability of dry matter (DM) and gas production indicate a possible tannin-induced depression for a number of browse species such as *A. dolichocephala, A. hockii, A. melanoxylon, A. polyacantha* and *F. macrophyla.* The presence of tannins and its depressing effect on DM and N degradability has been recorded in *C. calothyrsus* [Palmer and Schlink, 1992] and a number of *Acacia* species [Woodward and Reed, 1989]. However, low tannin content browse species such as *A. schimperiana, C. siliqua* and *Enterolobium cyclocarpum* had lower gas production and DM degradation characteristics than expected. The effect of tannins on gas production, DM and protein degradability seem to depends on an array of factors such as molecular structure and reactivity than the content [Hagerman et al., 1992]. Differences in solubility and PD between browses may also be attributed to the inherent attributes of NDF and N concentrations. A significant effect of NDF on degradability of forages using nylon bag DM disappearance as shown here and gas production has been demonstrated before [Nsahlai et al., 1994].

Correlation analysis showed that NDF, ADF and lignin negatively affected DM degradation and gas production. This is in accordance with previous reports on the negative effects of NDF, ADF and lignin [Minson, 1982; Nsahlai et al., 1994; Nsahlai et al., 1995] on forage digestibility. Gas production was strongly related to DM degradation, however, gas production contributed more to the palatability variations than DM degradation. Gas production has been shown to be positively related to intake [Blummel and Ørskov, 1992] and microbial protein synthesis [Hillman et al., 1993).

Table 5. Change in cluster membership due to the use of chemical constituents, degradation constants or gas production as re-classification variables instead of palatability index (R).

Re-classification variables	Clusters based on R	New clusters based on reclassification variables				% Misclassification
		1	2	3	4	
Ash, N, NDF	1	6[c]	3	6	1	62.5
	2	1	2[c]	5	1	77.8
	3	1	0	4[c]	1	33.3
	4	1	1	1	6[c]	33.3
Ash, N, NDF, TP	1	6[c]	3	6	1	62.5
	2	2	2[c]	3	2	77.8
	3	1	0	4[c]	1	33.3
	4	0	1	2	6[c]	33.3
Ash, N, NDF	1	10[c]	2	3	1	37.5
AP, NDFP	2	4	1[c]	3	1	88.9
	3	2	1	2[c]	1	66.7
	4	4	0	1	4[c]	55.6
Ash, N, NDF, TC	1	6[c]	3	6	1	62.5
	2	1	2[c]	5	1	77.8
	3	1	0	4[c]	1	33.3
	4	1	1	1	6[c]	33.3
ED, a, c	1	7[c]	0	5	4	56.3
	2	2	4[c]	1	2	55.6
	3	2	0	1[c]	3	83.3
	4	1	1	3	4[c]	55.6
NDF, b, c	1	4[c]	6	4	2	75.0
	2	1	5[c]	1	2	44.4
	3	1	1	4[c]	0	33.3
	4	1	2	5	1[c]	88.9
AG, BG, CG	1	3[c]	7	3	3	81.2
	2	5	2[c]	1	1	77.8
	3	1	0	3[c]	2	50.0
	4	2	1	3	3[c]	66.7

[c] refers to number of species that fall in the same cluster as with R; N: nitrogen; NDF: neutral detergent fibre; AP: acetone-soluble phenolics; NDFP: fibre bound proanthocyanidins; TP: total phenolics; TC: Total soluble proanthocyanidins; a: the zero time intercept; b: the slowly degradable fraction; c: rate of dry matter degradation; AG: asymptotic gas production; BG: time after incubation at which half of the asymptotic gas has been formed; CG: constant determining the sharpness of the switching characteristics of the profile.

The strong negative (NDF, ADF, lignin) and positive (N, NDFN, PD, AG) relationships between palatability and chemical constituents reveal the possibility of predicting palatability or DM intake. Although the coefficients of determination (R^2) between palatability, DM intake and other attributes studied were low (Table 4), they are however reasonable and the parameters can be used alongside desirable agronomic

attributes (e.g. persistence, high foliage yield and rapid regrowth ability) to select and classify potential fodder materials into a few categories. A detailed study of a member of each class could then provide specific recommendations for that particular class.

Palatability, like digestibility, is a forage characteristic [Dulphy and Demarquilly, 1983] generally measured in animals under standardized conditions. Numerous factors such as breed, age, body condition, external temperature and humidity are known to affect appetite. The most extensive studies on factors causing variation in intake of green cut forages were performed by Adrieu et al. [1981], Demarquilly and Adrieu [1992] and Kaitho et al. [1997]. The main factors affecting ingestibility of green forages are plant family and species, form, stage and cycle of growth. The inverse relationship between tannin levels in forages and palatability, voluntary intake, digestibility or N retention in some mammalian herbivores is well established [Robbins et al., 1987; Silanikove et al., 1994; Silanikove et al., 1996]. Reduced palatability, low rate of evacuation of digesta out of the rumen and toxic effects are factors that were considered in the explanation of the negative effects of tannins on feed intake in ruminants [Kumar and Singh, 1984; Provenza, 1995]. The poor correlation between the current methods of tannin analysis suggests that a greater understanding of the types and amount of tannins present in browse species is needed, together with the development of methods aimed at correctly quantifying biologically "active" tannins [McLeod ,1974]. Only through detailed studies can the influence of such compounds on the nutritional value of forages be accurately assessed.

Prior to 1950, a concept of "nutritional wisdom", embracing the idea that animals possess an instinct which enables them to select a diet best suited to their nutritional requirements, was often accepted. Tribe [1950] reviewed the evidence on the subject with all types of animals and found it "most conflicting", however, he concluded that an animal's feeding behaviour does not necessarily reflect its true nutritional requirements. Arnold [1964] stated that most mammals exhibit very little nutritional wisdom and that mammals will select a palatable but poor-quality diet in preference to an unpalatable nutritious diet even to the point of death. However, Martz et al. [1967] acknowledged that in theory the chemical composition of forages should influence their palatability. As indicated in Table 5, regardless of the re-classification variables used, the level of misclassification were rather high ranging from 33.3 to 88.9%. Thus, chemical constituents, degradability and microbial gas production are inadequate in clustering browses into classes as palatability did. The reason may be due to the fact that palatability is determined by several factors such as taste, odour and texture [Kaitho et al., 1997] some of which have no influence on either of the above predictors. Further research is needed to identify factors that could segregate species into different palatability groups.

Several conclusions can be made in regard to the browse species studied. The

phenolic components were more related to DM degradation and gas production than palatability and DM intake. Chemical composition attributes such as N, NDF, NDFN, ADF and lignin are essential in describing the nutritive value of browses. Cluster groups developed using palatability as classifying variable are different than the ones formed by using chemical composition attributes, gas production parameters or dry matter degradation characteristics.

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Chapter 5

Nitrogen in browse species: ruminal degradability and post-ruminal digestibility measured by mobile nylon bag and *in vitro* techniques

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Short title: Browse nitrogen degradability and digestibility
Submitted: Journal of the Science of Food and Agriculture

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Nitrogen in browse species: ruminal degradability and post-ruminal digestibility measured by mobile nylon bag and *in vitro* techniques

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Abstract

This study determined nitrogen degradability and digestibility of rumen undegradable nitrogen using mobile nylon bag (MNB) and pepsin/pancreatin *in vitro* technique (IV) of 40 browse species. Thirty Ethiopian highland sheep fitted with rumen cannulas were used in nitrogen (N) degradability studies. Six steers fitted with rumen cannulas were used in preparation of 16-h and 24-h ruminal undegraded residues and four steers fitted with distal abomasal cannulas were used in MNB technique. The browses varied widely in nitrogen solubility (15-468 g kg^{-1}), potential degradability (223-976 g kg^{-1}), rate of degradation (0.13-24 % h^{-1}) and effective degradability (135-821 g kg^{-1}).The apparent N digestibility (ND) of the rumen undegraded residues differed significantly ($P<0.05$) among browse species. No significant difference ($P>0.05$) was observed in ND of 16-h and 24-h residues. The ND of the 16-h residue varied from -218 to 759 g kg^{-1} and 169 to 851 g kg^{-1} for MNB and IV methods, respectively. Browse species with high tannin content such as *Acacia hockii, Acacia horrida, Acacia melanoxylon, Acacia persiciflora, Acacia salicina, Acacia saligna* and *Flemingia macrophylla* had high rumen by-pass and a low ND, while *Sesbania spp* and *A. nilotica* with low tannin contents underwent rapid and extensive dry matter and nitrogen degradation in the rumen. *Acacia sieberiana, Chamaecytisus palmensis, Erythrina spp, Gliricidia sepium, Samanea saman* and *Enterolobium cyclocarpum* had high by-pass and with a high proportion of the by-pass protein digested in the intestine, therefore these browses had a high potential as protein supplements. The ND measured by the MNB were significantly lower ($P<0.001$) than by the IV method. The correlation between MNB and IV was high and significant ($R^2=0.89$, $P<0.0001$) as also indicated by the regression equation (SE in parenthesis): MNB = -22.8 (4.55) + 1.0 (0.08)IV (RSD=10.56, $r^2=0.79$, $n=40$, $P<0.001$). The intercept of the linear relationship obtained was different from zero while the slope was not different from unity. Multiple regression analysis suggested that some of the unexplained variation could be accounted for by either nitrogen, acid detergent fibre or total phenolics levels in browses. The IV method is good for estimating digestibility of ruminally undegradable N, and hence its use would considerably reduce the need for delicate surgery and the elaborate procedures involving the MNB technique.

Key words: browse, nitrogen, degradability, digestibility, mobile nylon bag, *in vitro*

Introduction

Crude protein concentration and energy value of cereal crop residues and poor quality grasses are below animal requirements during much of the year and browses have been incorporated in the feeding systems to improve the nutritional status of ruminants. Leaves and fruits of leguminous browses can be used as protein supplements for ruminants and are commonly used as feeds in many agricultural systems. In parts of Africa, animal production is heavily depended on the availability of browse legumes, while in Australia, interest in fodder trees has focused mainly on native species, particularly the *Acacia* species, but novel browse legumes such as *Leucaena leucocephala* have also been introduced with some success. Most of the browse species contain variable amounts of structurally diverse secondary compounds such as phenolics, tannins (i.e. polyphenolics), terpenoids, amino acid derivatives, alkaloids, saponins or other compounds with anti-nutritional properties. The occurrence and the type of secondary compounds in browses largely determines their nutritive value and utility as feed sources.

In all-forage or forage based diets, protein quality of each dietary component is important in evaluating responses to supplementation. The new systems of protein evaluation (ARC, 1984; AFRC, 1992; Tamminga et al., 1994) partition feedstuff nitrogen into the amount degraded in the rumen and that which escapes ruminal degradation. Microbial protein production is influenced by the proportion of feedstuff N that is soluble and degradable in the rumen, in addition to the digestible energy available to fuel incorporation of ammonia and degradable protein into microbial protein. However, protein available for absorption post-ruminally is influenced by the amount of feedstuff N that is resistant to ruminal degradation plus microbial protein (Brown and Pitman, 1991). Therefore, the feed nitrogen (as true protein) which escapes rumen degradation but digested in the lower tract is one of the major elements in the determination of feed nitrogen value.

Several studies have been carried out to assess the digestibility of ruminal escape protein (Hvelplund, 1985; Peyraud et al., 1988; Frydrych, 1992), and the digestibility varies considerably across feeds (Krishnamoorthy et al., 1982). Values between 0.80 and 0.85 are adopted for the true digestibility of protein from temperate feeds and from microbial amino acids (ARC, 1984; van Bruchem et al., 1989). However, no data is available on intestinal digestibility of browses although they have been recognized as good protein supplements.

The nylon bag and mobile nylon bag techniques have been used for many years to predict protein degradability and digestibility of feeds (Michalet-Doreau, 1990). The mobile nylon bag (MNB) method is useful for assessing the digestibility of rumen undegradable feed protein in the intestine (Hvelplund, 1985; de Boer et al., 1987).

Incubation of feed with pepsin and pancreatin has also been used to determine digestibility of feed protein and post ruminal digestibility of formaldehyde-protected feeds (Vicini et al., 1983; Antoniewicz et al., 1988). Since the MNB is labourious, it was desirable to assess the accuracy with which pepsin/pancreatin procedure could predict results from the former. Therefore, the objectives of this study were to determine nitrogen degradability and estimate, using the mobile bag technique and pepsin/pancreatin *in vitro* digestion, the apparent intestinal digestibility of rumen undegraded N from various browse species.

Materials and methods

Samples of 40 browse species leaves were collected from feed offered (daily) during a palatability trial carried out at the International Livestock Research Institute (ILRI) seed multiplication centre, Zwai (Kaitho et al., 1996).The ILRI Zwai site is located in the Rift Valley of Ethiopia (8°00'N; 38°45'E) at an altitude of 1650 m above sea level, with an average bimodal rainfall of 600 mm. The soil is loamy sand classified as a vitric andosol with a pH (H_2O) of 8.05 (Kamara and Haque, 1988). All the browse species were deciduous and therefore shed their leaves during the dry seasons. Edible portions (leaves, petioles and twigs) were harvested from mature trees towards the end of rainy season and the samples dried under shade and later pooled per species.

Rumen Degradability

Thirty male Ethiopian highland sheep (23.4 kg SD=1.65) each surgically fitted with a rumen fistula were used for degradability studies. Each animal was fed native hay (CP=6%, NDF=72.4%) *ad libitum* and supplemented with 150 g wheat bran (CP=16.6%, NDF=46.9%) daily. After 15 days of adaptation, degradability of each browse species was determined using the nylon bag technique (Mehrez and Ørskov, 1977) in three sheep selected at random. Air-dried leaves were milled (2.5 mm screen) and about 2.5 g weighed per nylon bag (14 cm x 8 cm, 41μm pore size, Polymon, Switzerland) and incubated for 0, 3, 6, 12, 24, 48, 72, 96 120 and 336 h. After incubation the bags were washed using a non-automatic washing machine (Tefal alternatic, Finland). The water was changed five times, with each cycle lasting 5 minutes. The bags were dried in a forced-draught oven at 60°C for 48 h, cooled in a desiccator and weighed.

Mobile nylon bag method

Browse samples were ground through 2.5 mm screen, weighed into nylon bags (12 cm x 14 cm; 41 µm pore size; Polymon, Switzerland) and incubated in six rumen

fistulated steers (650 kg; SD=15.2). Each steer was fed native hay *ad libitum* and supplemented with 2 kg wheat middlings (CP=16.3%, NDF=40.1%). Each browse species was incubated in three animals for a duration of either 16-h or 24-h. The 16 and 24-h incubations were chosen to approximate digestion of feed material that escaped the rumen at the rates of 6 and 4% h^{-1}, respectively. After incubation, the bags were washed in cold water using a washing machine (Tefal alternatic, Finland) for 30 minutes. The recovered residues were dried at 50°C, pooled per species and incubation time and ground through a 1-mm sieve. The residues thus treated were weighed at a rate of 0.4 g per mobile nylon bag (6 cm X 7 cm, same material as above) which was subsequently heat-sealed. Sixteen bags were used for each incubation time per browse species. Prior to intestinal incubation, bags were incubated in 0.01 M HCl solution containing one gram per litre pepsin (activity 1:10,000) for 1 h at 39°C at a constant pH of 2 in an agitator.

The intestinal incubation was replicated in four steers (265 kg; SD=9.1) fitted with ruminal cannula and a distal abomasal cannula in a complete randomized-block design. The steers were fed native hay *ad libitum* and 2 kg wheat middlings as supplement. After an adaptation period of 10 days, 4 bags were inserted in the abomasum every 20 minutes from 6:00 to 12:00 h and 14:00 to 20:00 h during each of the 2 days (day 11 and 13). Replicate bags were divided over the four incubation periods. After incubations, faeces were collected at each defecation and washed in a sieve to recover bags which were frozen immediately. Only bags recovered within 48 h after insertion were used for further analysis. When the collection of bags had stopped, bags were thawed and washed with cold water in a washing machine (Tefal alternatic, Finland) for 8 cycles. After washing, bags were oven-dried at 50°C for 72 h and weighed. The residues were pooled per browse species, incubation time and animal, ground in a mortar and analysed for DM, ash and N.

The N determined on the 16-h and 24-h ruminal residues will be termed rumen undegradable N suffixed by the incubation times (N_16 , N_24), while the fraction of the residue that undergoes digestion at the post-ruminal gut will be termed digestible N suffixed by the length of ruminal incubation (ND_16, ND_24). The nitrogen in the 336-h residue is referred to as truly indigestible nitrogen (U).

In vitro digestibility (IV) method

The 16-h ruminal residue (0.5 g) was incubated in 20 ml solution of 0.075 M HCl pepsin (2 g l^{-1}, Merck, Darmstadt, Germany) at 39°C in a shaking water-bath for 2 h according to the method described by Antoniewicz et al. (1992). The solids were allowed to sediment out and the liquid was decanted through nylon bag cloth (same material as above) and further washed three times with distilled water. The deposit on the nylon

bag cloth was quantitatively washed back into the vessel using 0.1 M phosphate buffer, pH 7.4 (80 ml 0.2 M NaH_2PO_4 + 420 ml 0.2 M Na_2HPO_4 made up to 1 l with distilled water) and digested with 20 ml of pancreatin (Merck, Darmstadt, Germany) in the same buffer (final concentration 2 g l^{-1}) for 2 h in a shaking water-bath at 39°C. More buffer (about 20 ml) was added and the incubation mixture left overnight without shaking (39°C). The residue was filtered through ash-free filter paper (Whatman No. 1), washed with warm distilled water and wet-ashed with the filter paper for Kjeldahl-N determination. Results were corrected against blank (enzyme + filter).

Chemical analysis

Analysis for dry matter (DM), ash and Kjeldahl nitrogen (N) were according to AOAC (1990) standard procedures. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were analysed using the method of van Soest and Robertson (1985). Nitrogen that is insoluble in neutral detergent (NDFN) and acid detergent (ADFN) were assayed using the Kjeldahl method. Total water-soluble phenolics (TP) were determined in the filtrate following water extraction. Tannins in the filtrate were transformed to a blue-coloured product by Folin-Denis reagent and sodium carbonate (Kaitho et al., 1993). The intensity of the colour was measured at 760 nm. The content of total phenolics was calculated using a calibration line prepared using tannic acid (*Sigma*, T0125) as the standard compound (substrate). Colorimetric determination of condensed tannins (TC) was done according to the method of Porter et al. (1986). Acetone-soluble polyphenolics (AP) in browses were determined by precipitation with trivalent ytterbium (Reed et al., 1985). Neutral-detergent insoluble proanthocyanidins (NDFP) were determined by heating 2 mg of NDF at 95°C for one hour in n-butanol containing 5% concentrated HCl and the absorbance read at 550 nm (Reed at al., 1982).

Calculations and statistical analysis

The results of crude protein (CP) disappearance from nylon bags were fitted to the exponential equation of Ørskov and McDonald (1979) using non-linear regression (SAS, 1987):

$$Y = a + b(1 - e^{-ct})$$

where Y is the disappearance at time t, a is the zero time intercept, b slowly degradable fraction and c the rate constant. The potential degradability (PD) was calculated as (a+b). A passage rate (k_p) of 4% h^{-1} was assumed in order to calculate N effective

degradability (NED):

$$NED = a + \frac{bc}{k_p + c}$$

Residual CP at the various stages of incubation were also expressed as fractions of original amounts incubated and the results fitted to the model described by Robinson et al. (1986):

$$R_t = U + (1000 - W - U) * e^{-k_d t}$$

Where R_t = residue at time t
U = truly indigestible residue (336-h incubation)
W = water soluble fraction (0 h incubation)
K_d = rate of degradation (% / h)

The proportion of crude protein escaping rumen degradation (BP) was calculated from the equation (Perera et al., 1992):

$$BP = U + D(\frac{k_p}{k_p + k_d})$$

where k_p = the passage rate (k_p) of 4 % per hour
D = the potentially degradable proportion (1000-W-U).

Rumen degradable protein (RDP) was calculated as:

$$RDP = W + D(\frac{k_d}{k_p + k_d})$$

Similarly, intestinal digestible protein (IDP) was estimated as:

$$IDP = D(\frac{k_p}{k_p + k_d})$$

Nitrogen degradability characteristics were regressed on both chemical constituents and corresponding DM degradability characteristics reported elsewhere (Kaitho et al., 1997) and using a stepwise procedure (SAS, 1987) mixed models were constructed. Variables were included in the models when they contributed significantly ($P<0.15$) to

the relationship. Some equations based on the mixed models (type two) as proposed by Nsahlai et al., (1995) were:

$$P\_N \approx P\_DM(1-\beta)$$

where P_N and P_DM are corresponding N and DM degradability characteristics, respectively, and β the regression of the deviations of the ratio P_N:P_DM from unity on chemical constituents.

The GLM procedure (SAS, 1987) was used to determine the effects of browse species and animal on the results of mobile nylon bags according to the following model:

$$Y_{ijk} = \mu + M_i + A_j + MA_{ij} + e_{ijk}$$

where

Y_{ijk} = disappearance of DM or N after intestinal incubation,
μ = mean,
M_i = browse species effect
A_j = animal effect
Ma_{ij} = interaction between browse species and animal, and
e_{ijk} = residual error, assumed to be normally and independently distributed.

Regression analysis was carried out to find the relationship between rumen *undegradable nitrogen* (N_16, N_24) and *digestible nitrogen* (ND_16, ND_24). The N digestibility measured with the MNB and *in vitro* methods was also compared by the same method. A multiple regression equation was established between ND_16, IV_16 and chemical composition attributes of browse species using the stepwise method. The variable entry criterion was set at 0.15 probability level of significance and elimination of certain early entry variables if they are made redundant by new variables allowed in the equation.

Results

Chemical composition and tannin content of browse species are shown in Table 1. The crude protein content was high (>250 g kg^{-1}) in the leguminous browses especially in *Sesbania spp, Acacia polyacantha* and *Albizia schimperiana*. Low levels were observed in non-leguminous species such as *Casuarina* and *Ceratonia*. The fibre-bound nitrogen (NDFN and ADFN) was particularly high in *Calliandra calothyrsus, Acacia hockii, Acacia horrida, A. polyacantha* and *Sesbania sesban var.* bicolor. Different levels of tannins were detected using the various methods (AP, NDFP, TP and TC).

Table 1. Chemical composition (g kg^{-1}) of the browse species.

Species	OM	CP	NDF	NDFN	ADF	ADFN	Lignin	AP	NDFP	TP	TC
Acacia coriacea	894	125	573	16	417	13	220	97	41	25	22
Acacia dolichocephala	946	138	525	33	449	29	246	282	113	157	81
Acacia hockii	926	163	396	45	304	26	124	329	25	201	12
Acacia horrida	843	156	394	40	252	21	118	125	103	52	36
Acacia melanoxylon	946	144	595	26	479	20	292	93	53	91	35
Acacia microbotrya	943	156	412	32	282	20	169	290	18	140	22
Acacia nilotica	956	194	391	35	282	17	76	71	43	30	3
Acacia persiciflora	908	175	525	31	388	21	202	116	29	72	19
Acacia polyacantha	913	281	498	48	297	26	133	89	101	196	14
Acacia salicina	831	144	463	27	287	21	141	175	110	74	39
Acacia saligna	883	150	447	29	297	18	146	160	73	52	45
Acacia sieberiana	892	206	526	32	354	20	212	205	85	25	20
Acacia venosa	918	219	491	43	366	30	175	294	23	59	21
Albizia schimperiana	926	256	646	37	478	29	254	233	19	46	5
Atriplex halimus	705	131	401	26	211	9	145	134	7	6	3
Atriplex nummularia	656	175	379	37	171	19	103	342	7	0	2
Atriplex rhagodiodes	707	156	397	23	214	7	76	233	7	4	3
Calliandra calothrysus	890	225	505	51	440	31	190	392	54	88	14
Casuarina cunninghamiana	921	106	613	13	459	10	195	415	29	93	19
Casuarina equisetifolia	922	88	450	11	334	9	137	518	21	106	40
Casuarina glauca	949	81	694	10	523	9	208	403	49	59	26
Ceratonia siliqua	941	100	506	23	401	18	196	492	60	133	7
Chamaecytisus palmensis	947	213	449	37	255	12	81	241	6	34	1
Entada abyssinica	904	194	519	37	377	28	222	267	27	21	14
Enterolobium cyclocarpum	894	213	416	36	279	25	123	216	55	16	3
Erythrina abyssinica	873	225	600	25	429	10	110	329	69	9	1
Erythrina bentipoeme	890	213	560	28	398	11	87	144	7	17	2
Erythrina burana	884	188	554	30	412	10	81	82	5	11	2
Flemingia macrophylla	910	175	584	27	452	17	188	341	75	48	79
Gliricidia sepium	872	244	450	42	284	19	155	107	56	12	2
Leucaena pallida	828	194	377	35	220	21	102	134	30	21	12
Leucaena leucocephala	895	156	414	41	262	20	144	333	46	84	30
Leucaena pulverulenta	835	188	419	42	321	35	187	74	25	29	4
Moringa stenopetala	866	231	276	36	255	14	56	88	35	24	2
Samanea saman	935	219	446	23	344	14	168	104	13	65	11
Sesbania sesban	904	306	287	28	199	25	55	57	103	22	20
Sesbania sesban var. bicolor	899	306	220	48	146	15	50	96	20	21	2
Sesbania goetzei	892	250	430	44	285	21	152	77	7	25	3
Tamarindus indica	927	138	484	22	324	11	121	287	85	14	8
Tipuana tipu	896	169	467	21	321	14	129	106	29	65	16

OM: organic matter (g kg^{-1} DM); CP: crude protein (g kg^{-1} DM); NDF: neutral detergent fibre (g kg^{-1} DM); NDFN: neutral detergent fibre bound nitrogen (g kg^{-1} NDF); ADF: acid detergent fibre (g kg^{-1} DM); ADFN: acid detergent fibre bound nitrogen (g kg^{-1} ADF); CP); AP: acetone-soluble phenolics (g kg^{-1} DM); NDFP: NDF fibre bound proanthocyanidins (550 nm OD per g NDF); TP: total phenolics (g kg^{-1} DM);TC: Total soluble proanthocyanidins (g kg^{-1} DM).

Rate of degradation of potentially degradable N-fraction varied from -0.1 to 19.0 % h^{-1} as estimated by Ørskov and McDonald (1979) and Robinson et al. (1986) models (Table 2). Both models had similar rates of degradation for most of the browse species. Degradability constants for browse species such as *Acacia dolichocephala, A. hockii, Casuarina cunninghamiana, Casuarina equisetifolia, Casuarina glauca, Ceratonia siliqua* and *Entada abyssinica* could not be estimated by the Ørskov and McDonald (1979) model because the curves could not converge, and therefore the estimates were unrealistic (Figure 1). Similar results were observed when *C. cunninghamiana, C. glauca* and *Acacia melanoxylon* data was fitted to the Robinson et al. (1986) model. Effective degradation was high in *Sesbania spp, Moringa stenopetala* and *Gliricidia sepium*. Species such as *A. horrida, Acacia microbotrya* and *C. calothyrsus* had high potential degradabilities and low effective degradabilities (<500 g kg^{-1}). The U was particularly high in *A. dolichocephala, A. melanoxylon, Acacia venosa, C. cunninghamiana, C glauca, Entada abyssinica and Flemingia macrophylla*. The estimated BP, RDP and IDP varied widely among the browse species. Browse species such as *A. dolichocephala* and *Entada abyssinica* had high BP and low RDP and IDP.

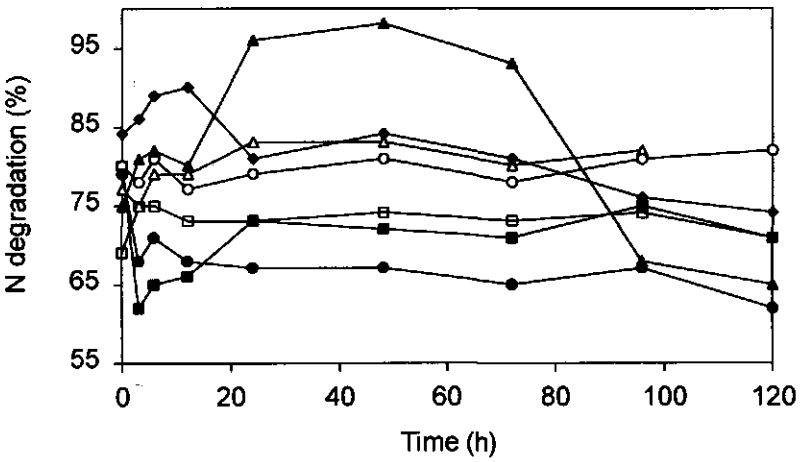

Figure 1. Nitrogen degradability (g kg^{-1}) of *Acacia dolichocephala*,○; *A. hockii*, ●; *Casuarina cunninghamiana*, □; *C. equisetifolia*, ■; *C. glauca*,△; *Ceratonia siliqua*,▲ and *Entada abyssinica* ,♦.

Table 2. Nitrogen degradability constants (g kg^{-1}), indigestible nitrogen, by-pass protein, rumen degradable protein and intestine degradable protein of browses.

	Degradability constants									
Species	W	PD[$]	C[$]	ED[*]	k_d[*]	U[*]	D[*]	BP	RDP	IDP
Acacia coriacea	319	579	1.6	409	1.2	404	277	616	384	212
Acacia dolichocephala	64	-	-	-	0.1	874	62	936	64	62
Acacia hockii	100	-	-	-	0.7	556	344	853	147	296
Acacia horrida	146	837	0.6	267	1.0	408	446	763	237	355
Acacia melanoxylon	194	468	0.1	205	-	798	8	799	201	1
Acacia microbotrya	50	884	0.9	239	1.3	319	631	795	205	476
Acacia nilotica	198	854	8.7	686	4.9	47	755	385	615	338
Acacia persiciflora	76	340	1.1	147	1.0	613	311	864	136	251
Acacia polyacantha	15	435	13.0	356	5.5	432	553	665	335	233
Acacia salicina	85	439	1.1	180	0.9	549	366	848	152	300
Acacia saligna	186	833	0.9	333	0.9	316	498	726	274	410
Acacia sieberiana	319	693	5.5	561	3.4	238	443	478	522	240
Acacia venosa	164	316	5.4	262	10.5	695	141	734	266	39
Albizia schimperiana	327	516	1.7	396	6.6	544	129	593	407	49
Atriplex halimus	269	843	12.9	735	7.1	122	609	341	659	219
Atriplex nummularia	444	898	5.7	742	5.8	118	438	296	704	179
Atriplex rhagodiodes	394	899	5.0	711	5.3	126	480	333	667	207
Calliandra calothrysus	221	992	0.3	297	0.3	280	499	745	255	465
Casuarina cunninghamiana	231	-	-	-	-	830	-61	829	171	0
Casuarina equisetifolia	108	-	-	-	0.7	657	235	858	142	201
Casuarina glauca	130	-	-	-	-	875	-5	875	125	-1
Ceratonia siliqua	139	-	-	-	0.3	538	323	839	161	301
Chamaecytisus palmensis	344	952	4.4	707	4.4	50	606	340	660	290
Entada abyssinica	35	-	-	-	1.6	896	69	953	47	57
Enterolobium cyclocarpum	354	666	5.3	553	3.6	286	360	475	525	189
Erythrina burana	220	760	9.0	625	19.0	376	404	446	554	70
Erythrina abyssinica	58	823	11.1	661	17.8	309	633	425	575	116
Erythrina bentipoeme	151	779	11.4	648	9.3	239	610	422	578	183
Flemingia macrophylla	127	256	0.2	135	-0.1	686	187	876	124	190
Gliricidia sepium	288	801	10.7	689	3.7	98	614	416	584	317
Leucaena leucocephala	72	556	2.4	285	1.4	318	610	771	229	452
Leucaena pallida	199	857	1.5	413	1.6	163	638	623	377	460
Leucaena pulverulenta	81	518	3.6	318	3.1	443	476	713	287	270
Moringa stenopetala	393	964	4.8	744	4.9	46	561	299	701	253
Samanea saman	159	663	8.1	527	7.3	322	519	507	493	184
Sesbania goetzei	247	856	6.0	652	4.5	93	660	404	596	310
Sesbania sesban	468	976	6.9	821	6.9	34	498	217	783	183
Sesbania sesban var. bicolor	236	957	6.8	736	6.2	48	716	327	673	280
Tamarindus indica	80	764	8.1	579	6.5	186	734	466	534	280
Tipuana tipu	170	713	9.5	583	5.0	222	608	492	508	270

[$]: based on Ørskov and McDonald (1979) model; [*]: based on Robinson et al. (1986) model; W: solubility; PD: potential degradability; ED: effective degradability; C: rate of degradation (% h^{-1}); k_d: rate of degradation (% h^{-1}); D: potentially degradable fraction; U: indigestible nitrogen (g kg^{-1} of original forage N); BP: by-pass N (g kg^{-1} of original forage N); RDP: rumen degradable protein (g kg^{-1} CP) and IDP: intestine degradable protein (g kg^{-1} CP).

Table 3. Equations for predicting N degradability from corresponding DM degradability[a] estimates with or without chemical constituents.

Dependent[b] variable	Equation[c] (n=33)	RSD	r^2
N_W	39.78 (49.780) + 0.74 (0.198)DM_W	102.37	0.29
N_PD	125.92 (101.667) + 0.94 (0.154)DM_PD	145.59	0.53
N_C	0.29 (0.896) + 0.82 (0.145)DM_C	2.43	0.49
N_ED	-64.28 (58.588) + 1.13 (0.121)DM_ED	103.09	0.73
Mixed equations (type one)			
N_W	-459.38 (212.628) + 1.11 (0.264)DM_W + 6.52 (2.430)N + 0.45 (0.252) NDF	94.21	0.40
N_W	-321.68 (201.550) + 0.88 (0.256)DM_W - 1.03 (0.398)TP + 6.36 (2.222)N + 0.38 (0.232)NDF	86.13	0.50
N_PD	-326.48 (290.980) + 1.28 (0.252)DM_PD + 0.76 (0.462)ADF	29.58	0.32
N_C	-6.48 (2.510) + 0.96 (0.159)DM_C + 0.13 (0.050)N +0.02(0.011)TP + 0.003 (0.0044)ADF	2.12	0.62
N_C	-10.22 (2.407) + 0.76 (0.120)DM_C + 0.17 (0.047)N + 0.02(0.009)CELL + 0.01 (0.005)HEMI	1.89	0.69
N_ED	-928.56 (145.606) + 1.57 (0.125)DM_ED + 5.94 (1.661)N + 1.05 (0.189)NDF	69.38	0.88
Mixed models (type two)			
N_W	DM_W(1-(1.25-0.02N-0.004HEMI))		0.32
N_W	DM_W(1- (2.13 - 0.03N - 0.003NDF + 0.01TP))		0.39
N_PD	DM_PD(1- (0.17 - 0.001ADF))		0.56
N_C	DM_C(1- (2.69 - 0.04N - 0.01CELL - 0.002HEMI))		0.62
N_C	DM_C(1- (2.80 - 0.04N - 0.01CELL- 0.002HEMI - 0.003TP))		0.66
N_ED	DM_ED(1- (1.21 - 0.02N -0.001NDF))		0.74
N_ED	DM_ED(1- (1.24 - 0.02N - 0.001NDF + 0.003TP))		0.78

[a] dry matter degradation characteristics refer to Kaitho et al. (1997); [b] N_W, N_PD, N_ED (in g kg^{-1}) , N_C (% h^{-1}) stand for N solubility, potential degradability, effective degradability and rate of degradation, respectively, and corresponding DM characteristics denoted by DM_W, DM_PD, DM_ED and DM_C. TP : soluble phenolics; CELL: cellulose; N: nitrogen; HEMI: hemicellulose and NDF: neutral detergent fibre (in g/kg). RSD: residual standard deviation of fitted equations; [c] standard errors are given in parentheses besides the regression coefficients.

The N_16 was significantly ($P<0.001$) higher than N_24 as depicted by the regression equation (SE in parenthesis):

N_16 = 0.20 (0.509) + 0.89 (0.010)N_24, (RSD=1.656, r^2=0.995, n=40, $P<0.001$).

Regression equations of N degradation characteristics on DM degradation characteristics are given in Table 3. The intercepts and slopes of regression of N degradability characteristics (solubility, potential degradability, rate constant, effective

Table 4. Average disappearance of DM and N in the rumen (g kg^{-1} original forage), intestine (g kg^{-1} rumen residue) and whole-tract (g kg^{-1} original forage) of browses measured with the nylon bag and *in vitro* methods .

Site	Rumen				Intestine			Whole-tract	
Species	DM_16	DM_24	N_16	N_24	ND_16	ND_24	IV_16	T16	T24
Acacia coriacea	79	58	409	461	267	250	577	567	596
Acacia dolichocephala	6	18	12	207	-218	-151	169	-203	87
Acacia hockii	102	68	327	331	-71	-96	194	279	267
Acacia horrida	117	105	281	305	70	118	344	331	387
Acacia melanoxylon	61	82	321	312	55	55	256	358	350
Acacia microbotrya	80	117	217	263	139	189	178	326	402
Acacia nilotica	438	342	712	816	585	546	765	880	916
Acacia persiciflora	94	86	263	272	89	168	321	329	394
Acacia polyacantha	138	105	452	444	208	201	334	566	556
Acacia salicina	164	158	187	268	97	175	329	266	396
Acacia saligna	137	89	195	299	139	273	416	307	490
Acacia sieberiana	82	87	599	644	281	282	554	712	744
Acacia venosa	102	95	355	394	324	209	387	564	521
Albizia schimperiana	106	110	486	467	293	283	457	637	618
Atriplex halimus	255	150	752	787	612	469	784	904	887
Atriplex nummularia	267	187	744	823	541	489	767	882	910
Atriplex rhagodiodes	179	165	701	769	570	490	710	871	882
Calliandra calothrysus	134	135	255	259	202	260	431	405	452
Casuarina cunninghamiana	73	75	267	265	234	377	614	439	542
Casuarina equisetifolia	108	110	314	268	220	221	681	465	430
Casuarina glauca	65	99	200	174	230	290	655	384	414
Ceratonia siliqua	56	55	150	45	-218	-232	266	-35	-177
Chamaecytisus palmensis	105	39	651	788	515	454	777	831	884
Entada abyssinica	94	133	128	187	168	249	325	274	389
Enterolobium cyclocarpum	166	140	580	649	291	368	479	702	778
Erythrina burana	89	44	648	712	480	339	780	817	810
Erythrina abyssinica	94	58	698	796	400	436	624	819	885
Erythrina bentipoeme	139	92	663	760	464	199	744	819	808
Flemingia macrophylla	58	72	213	184	62	137	307	262	296
Gliricidia sepium	182	133	654	781	483	431	734	821	875
Leucaena leucocephala	237	222	289	353	203	175	324	433	466
Leucaena pallida	63	104	403	490	47	172	215	431	578
Leucaena pulverulenta	161	136	369	443	165	210	423	473	560
Moringa stenopetala	355	151	715	843	561	368	620	875	901
Samanea saman	94	70	574	628	304	361	512	704	762
Sesbania goetzei	339	240	656	802	573	415	707	853	884
Sesbania sesban	521	357	818	916	759	663	851	956	972
Sesbania sesban var. bicolor	375	207	725	907	678	600	767	911	963
Tamarindus indica	122	52	618	758	330	299	500	744	830
Tipuana tipu	198	196	564	687	386	381	627	732	806
SED (n=4)	11.7	14.8			21.9	19.9	8.7		

DM_16: dry matter disappearance after 16-h incubation; DM_24: dry matter disappearance after 24-h incubation; N_16: Nitrogen disappearance after 16-h incubation; N_24: Nitrogen disappearance after 24-h incubation; ND_16: 16-h residue nitrogen digestibility (MNB method); ND_24: 24-h residue nitrogen digestibility (MNB method; IV_16: 16-h residue *in vitro* nitrogen digestibility; T16: whole-tract nitrogen digestibility based on 16-h residue; T24: whole-tract nitrogen digestibility based on 24-h residue.

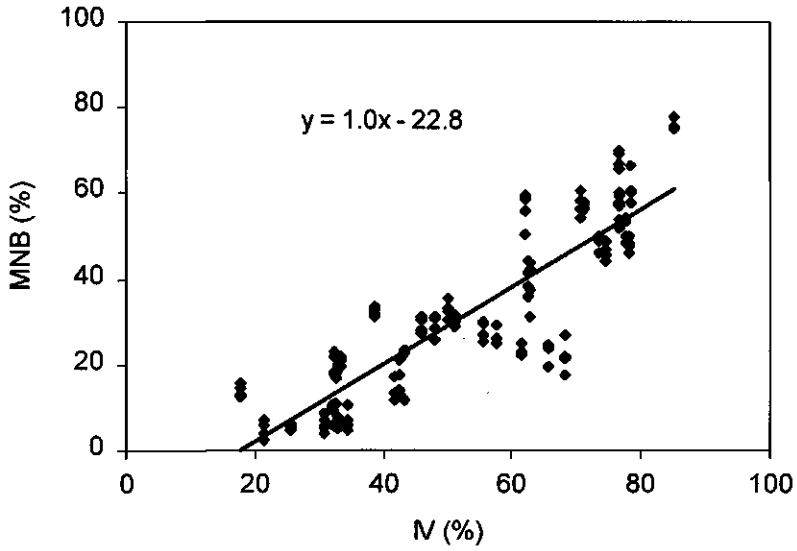

Figure 2. Relationship between N digestibility as measured by mobile nylon bag (MNB) and *in vitro (IV)* methods

degradability) on corresponding DM estimates were not different (P>0.05) from zero and unity, respectively. Addition of chemical constituents to the mixed models improved the accountable variations by 0.03-0.21.

The DM and N digestibility using MNB differed significantly (P<0.05) among browse species (Table 4). No significant (P>0.05) animal effects were observed on the DM and N digestibility. No significant difference (P>0.05) was observed between ND_16 and ND_24. The regression equation for this relationship was (SE in parenthesis):

ND_16 = -3.17 (2.521) + 1.15 (0.076)ND_24 , (RSD=8.80, r^2=0.86, n=40, P<0.0001).

The N digestibility measured with the MNB (ND_16) were significantly lower (P<0.001) than by the *in vitro* (IV_16) method. The correlation between ND_16 and IV_16 was high and significant (R^2=0.89, P<0.0001) as indicated in Figure 2 and in the following regression equation (SE in parenthesis):
ND_16 = -22.80 (4.545) + 1.01 (0.082) IV_16, (RSD=10.56, r^2=0.79, n=40, P<0.0001).

The intercept of the linear relationship obtained was different from zero while the slope was not different from unity. Mixed models were however established using stepwise regression to improve the precision of estimating ND_16 using (SE in parenthesis):

ND_16 = -12.75 (8.195) + 0.76 (0.071)IV_16 + 6.76 (1.344)N - 0.40 (0.125)ADF - 0.70 (0.279)TP (RSD=6.74, r^2=0.92, n=40, P<0.001).

The 24-h residue had higher whole-tract digestibility. Browse species such as *C. siliqua* or *A. dolichocephala* had negative digestibility, therefore they may not be suitable protein supplements.

Discussion

Recommended use of tanniferous forages is complicated by the effects of the stage of maturity, local environment and drying procedures on the phenolic content. Isolation and quantification of phenolics in plants are essential to studies on their nutritional and ecological effects (Waterman and Mole, 1994), since the commonly used calorimetric assays have many problems (Martin and Martin, 1982). However, there are a growing number of methods for assaying tannins in plants (Waterman and Mole 1994). A considerable variation in the level of phenolics was observed in this study, which depended not only on legume species, but also on the method of analysis. However, no single method will give results that are satisfactory in relation to nutritional effects because the chemical properties that are involved in the reactivity of polyphenols in colorimetric, gravimetric and/or precipitation assays may differ from the properties that underlie their nutritional or toxic effect (Reed, 1995).

Browses species such as *A. hockii, A. melanoxylon, A. venosa, C. cunninghamiana, C. Glauca and Entada abyssinica* had high BP, but their beneficial effect may be negated by a the low IDP observed. The latter effect could be linked with ability of tannins to bind with feed proteins and enzymes thus reducing their digestibility (Cheeke and Palo, 1995). Consequently, high tannin species such as *A. hockii, A. horrida, A. melanoxylon, Acacia persiciflora, Acacia salicina, Acacia saligna* and *F. macrophylla* had low digestibility of the rumen undegraded N.

Based on the amount of browse protein digested along the digestive tract, species such as *C. siliqua, A. dolichocephala and F. macrophylla* had low feed value as protein supplements. Some forage proteins are degraded to a large degree in the rumen (Ulyatt et al., 1975), and that was the case in *S. sesban, M. stenopetala, Atriplex spp* and *A. nilotica* containing low tannins leading to low by-pass protein. However, levels of anti-nutritional factors such as tannin, cannot be used alone to determine the suitability of a browse species as a protein supplement. Factors such as reactivity, structure, molecular weight and interactions of different secondary compounds in the plant are important (Barry et al., 1986; Waghorn et al., 1994).

Acacia sieberiana, Chamaecytisus palmensis, Erythrina spp, G. sepium, Samanea saman and *Enterolobium cyclocarpum* had medium BP and with a high proportion of the by-pass protein digested in the intestine, therefore these browses had a high

potential as protein supplements. It is frequently suggested that forages with comparatively high concentration of rumen-undegradable protein may be utilized more efficiently than those with high proportions of readily degradable protein (Buxton, 1996). Van Eys et al. (1986) associated the increased weight gain observed in goats supplemented with *Gliricidia, Leucaena* or *Sesbania* with the quantity and characteristics of rumen-degradable protein in the legumes and its effect on microbial protein production. However, Aii and Stobbs (1980) had earlier suggested that a considerable quantity of nitrogen in *Leucaena* may be resistant to ruminal degradation supporting the observation by Flores et al. (1979) that a supplement of *Leucaena* increased milk production to the extent similar to that of formaldehyde-treated casein. Nitrogen degradation results from this study indicated that the two models used (first order kinetics models) did not sufficiently described nitrogen degradation in a number of browses. This may be due to the fact that a number of the browse species have anti-nutritional factors that have negative effect on microbial population. Some of the browse species studied are known to have antibiotic and defaunating properties (Leng et al., 1992). Logistic models that assume degradation is influenced by activity of the bacterial population could be applicable in these cases (Robinson et al., 1986).

As indicated in Table 3, the strong relationship between DM and N degradation characteristics revealed the possibility of predicting N degradation using DM degradation characteristics. Chemical constituents accounted for some variation in N degradability characteristics but are inadequate predictors on their own. However, when used alongside DM characteristics there was an increase in prediction precision of N degradability coefficients. The indications from these regressions is that N digestibility is most likely to be low for species containing high concentrations of these constituents. Consequently, mixed models were useful in reducing the deviations of the intercept from zero. This was in accordance with previous observation on N degradability (Nsahlai et al., 1995).

Judging from the intercept of the regression relationship of ND_16 on IV_16, the IV method overestimated post-ruminal N digestibility relative to the MNB method. A similar observation was made by van Straalen et al. (1993). Although the relationship between ND_16 and IV_16 accounted for 79% of the variation, IV_16 on its own may be a poor predictor of intestinal protein digestibility. Fortunately, multiple regression analysis suggested that the prediction was better when *in vitro* digestibility was adjusted for nitrogen, ADF or TP levels in browses. The mobile nylon bag technique, if including passage from duodenum to faeces, somewhat overestimates protein digestibility values (Hvelplund, 1985). This technique, however, has some properties, such as relative good reproducibility (de Boer et al., 1987) and linear relationship to *in vivo* data (Hvelplund, 1985), which makes it suitable for routine estimation of intestinal digestibility and ranking feeds according to that characteristic.

Most of the browse species evaluated in this trial provided moderate levels of by-pass N with a digestibility ranging from -21.8 to 75.9% which was definitely lower than what was observed for temperate feeds (van Bruchem et al., 1989). This information could allow for low nitrogen feeding strategies aimed at reducing livestock environmental impact and increasing protein feeding efficiency (Tamminga, 1982). The nitrogen content of browses does not fully account for their nutritive value as protein supplements. Factors such as nitrogen degradability in the rumen and digestibility of the by-pass nitrogen are of paramount importance and these are subject to factors such as tannin, fibre or lignin concentrations of the browses. It is recommended that the *in vitro* N digestibility method should be used alongside N, ADF or total phenolic levels to predict digestibility of ruminally undegradable N as this method would considerably reduce the need for delicate surgery and the elaborate procedures involved in the mobile nylon bag technique.

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Chapter 6

Utilization by sheep of browse supplements with varying tannin levels: 1. intake, digestibility and live weight changes

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Abstract

The effect of tannins in browse supplements on intake, digestibility and live weight changes was evaluated using sixty-six male Ethiopian Menz sheep in a 90-day trial. Teff straw (*Eragrostis tef*) was fed ad-libitum (control diet), or supplemented with 190 g air dried leaves of lablab (*Dolichos lablab*), tagasaste (*Chamaecytisus palmensis*), leucaena (*Leucaena leucocephala*), goetzei *(Sesbania goetzei),* and six accessions of *Sesbania sesban* (S1190, S1198, S2024, S10865, S15019 and S15036) in a completely randomized block design. Animals supplemented with forage legumes with low tannin levels such as lablab, S1190, S1198, and S10865 tended to have a lower teff straw intake than those on the control diet. The converse was true for those fed the high tannin supplements such as S15019, S15036, S2024 and goetzei. Supplementation significantly ($P<0.05$) increased total dry matter intake (DMI) and live weight gains(LWG). The animals on the control diet lost weight (-1.9 g $kg^{-0.75}$), while the supplemented animals gained daily between 2.9 and 4.4 g $kg^{-0.75}$. Leucaena supplementation promoted higher ($P<0.05$) LWG than lablab, S1190 and goetzei. With increasing tannin levels (among *Sesbania* accessions), there was an increase (S1190<S1198<S10865<S15019) followed by a decrease (S2024>S15036>goetzei) in LWG. The digestibilities of total DM and the supplements did not differ significantly ($P<0.05$) among the diets, although the neutral detergent fibre (NDF) digestibility decreased significantly ($P<0.05$) with supplementation. The control diet had significantly ($P<0.05$) higher NDF digestibility than the leucaena, S10865, S15019, S15036 and S2024 supplemented diets. The DM degradability of the forages was carried out in thirty-three rumen-fistulated male sheep blocked on live weight and randomly assigned within blocks to the forages in a completely randomized block design. Lablab had lower water solubility and higher ($P<0.05$) truly undegradable dry matter than the other browse supplements. With increasing tannin levels (among *Sesbania* accessions), there was significant decrease ($P<0.05$) in rate of degradation. Increasing levels of tannin was also associated with a general increase in escape DM.

Key words: browses, intake, digestibility, live weight gain, degradability, sheep

Introduction

In tropical and subtropical regions, pasture grasses and cereal residues are frequently low in protein and therefore cannot support high levels of ruminant animal production. Legume supplementation of grass/cereal residues diets with <7% crude protein, has been shown to increase dry matter intake and improve animal performance [Minson and Milford, 1967]. Leaves of leguminous browses are good protein supplements for ruminants and are an integral part of many agricultural production systems. However, most of these browse and forage legumes are known to contain simple or complex phenolic compounds [D'Mello, 1992]. Nutritively, the large differences in response noted when these fodders [Wiegand et al., 1995; Nsahlai et al., 1993] are fed as protein supplements have been attributed to the differences in the levels of phenolics.

These polyphenolic compounds are sometimes accredited with beneficial attributes in ruminant nutrition by virtue of their capacity to suppress bloat, reduce the effects of intestinal nematodes on productivity [Niezen et al., 1993], and to prevent excessive degradation of high-quality leaf protein in the rumen and hence an improvement in animal performance [Wang et al., 1994]. The clear implication is that condensed tannins protect labile plant proteins in the rumen and consequently increase the supply of high-quality protein entering the duodenum [Barry and Manley, 1984; Barry et al., 1986; Mangan, 1988]. However, when forage legumes contain high levels of condensed tannins (proanthocyanidins), intake and apparent digestion of protein and carbohydrates are depressed [Barry and Duncan, 1984; Barry and Manley, 1984; Reed et al., 1990]. It is presumed that the condensed tannins released post-ruminally do not exert any deleterious effects subsequently, since pH conditions do not allow any further reactions with dietary or endogenous proteins.

Considerable variation in animal response [Said and Tolera, 1993] and failure to achieve target response [Tanner et al., 1990] have been reported when forages were supplemented to sheep fed roughage diets. This variation may partly be attributed to the quality of forage supplements, as well to the quality of basal roughage diets [Umunna et al., 1995]. Recent research determined that there is a wide range among accessions of *S. sesban* and *S. goetzei* in the content of soluble and insoluble proanthocyanidins [Nsahlai et al., 1993; Wiegand et al., 1995]. The present paper describes the response of sheep consuming teff straw to supplementation with foliage of leucaena, tagasaste and different accessions of sesbania with varying tannin levels. Foliage of lablab was included for comparative purposes.

Material and methods

Two experiments were conducted at the International Livestock Research Institute (ILRI) research farm at Debre Zeit, Ethiopia. Air-dried leaves of lablab (*Dolichos lablab*), tagasaste (*Chamaecytisus palmensis*), leucaena (*Leucaena leucocephala*), *goetzei (Sesbania goetzei)* and six accessions of *Sesbania sesban* (S1190, S1198, S2024, S10865, S15019 and S15036) were used to supplement sheep fed teff straw (*Eragrostis tef)*. These forages were chosen because previous research had indicated that they had good agronomic performance and that their tannin levels were variable. All the forages were grown on the farm (1850 m above sea level; annual rainfall 800 mm).

Experiment 1

Sixty-six male Ethiopian Menz sheep (19.4 kg ; SD=1.81; average age of 14 months) bought from nearby markets and after undergoing standard quarantine procedures for 21 days were blocked on live weight and randomly assigned within block the 11 dietary treatments in a completely randomized block design. Unchopped teff straw (*Eragrostis tef*) was given alone (control diet) or supplemented with 190 g dried forage of lablab, tagasaste, leucaena, *goetzei* and six accessions of *S. sesban* (S1190, S1198, S2024, S10865, S15019 and S15036). Teff straw was fed *ad libitum* (i.e. about 1.5 times the previous day's intake) and no mineral lick was offered. All the sheep had access to water *ad libitum*. The amount of supplement fed (190 g) was chosen such that the consumed diet contained 6-8% CP which, according to Whiteman [1980] is sufficient for microbial activities in the rumen. The legume supplement was fed in plastic buckets. The quantity of teff straw and supplements offered and refused were recorded daily during the 90-day period. The refusals were removed, weighed and sampled before the morning feeding (08.00 h). The sheep were weighed fortnightly.

The feeding trial was followed by a 10-day digestibility trial. All the animals were put in metabolic crates (in two groups) and allowed 3 days to adapt to the crates and the faecal collection bags. Complete collections of faeces and urine were carried out while, ensuring no contamination of faeces with urine. During the digestibility trial, forages and refusals were sampled daily for the determination of dry matter and nitrogen. Faeces and urine (10% of daily production) were pooled for each animal and subsampled, while the remainder of the faeces were kept frozen pending subsequent use in a decomposition and mineralization study.

Experiment 2

Thirty-three male rumen-fistulated Ethiopian Menz sheep (25.4 kg; SD=1.12; average age of 20 months) were blocked on live weight and randomly assigned within blocks to the forages in a completely randomized block design. Each animal was fed Suluta hay (CP=6%, NDF=72.4%) *ad libitum* and supplemented with 150 g wheat bran (CP=16.6%, NDF=46.9%) daily. After 15 days of adaptation, rumen degradability of each forage was determined using the nylon bag technique [Mehrez and Ørskov, 1977] in three sheep selected at random. Air-dried samples were milled (2.5 mm screen), and about 2.5 g weighed per nylon bag (14 cm x 8 cm, 41μm pore size, Polymon, Switzerland) were incubated for 0, 3, 6, 12, 24, 48, 72, 96, 120 and 336 h. After incubation, the bags were washed using a non-automatic washing machine (Tefal alternatic, Finland) without spinning. The water was changed five times, with each cycle lasting 5 minutes. The bags were dried in a forced-air oven at 60°C for 48 h, cooled in a desiccator, and weighed.

Chemical analysis

Samples of feeds and refusals were ground to pass a 1- mm screen using a Wiley mill, while frozen faecal samples and rumen incubated residues were ground using a mortar and pestle. Dry matter was assayed on the offered and refused feed and faeces using the method described by the AOAC [1990]. Analyses for ash and Kjeldahl nitrogen (N) in forages, faeces and nylon bag residues were according to AOAC [1990] standard procedures. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were analysed using the method of van Soest and Robertson [1985]. Total water soluble phenolics (TP) were determined after water extraction. After filtration the tannins were transformed to a blue-coloured product by Folin-Denis reagent and sodium carbonate [Kaitho et al., 1993]. The intensity of the colour was measured at 760 nm. The content of total phenolics was calculated using a calibration line prepared using tannic acid (Sigma, T0125) as the standard compound (substrate). Acetone-soluble polyphenolics (AP) in feeds were determined by precipitation with trivalent ytterbium [Reed et al., 1985]. Neutral-detergent insoluble proanthocyanidins (PA) were determined by heating 2 mg NDF samples at 95°C for one hour in n-butanol containing 5% concentrated HCl and then absorbance was read at 550 nm [Reed at al., 1982]. Results were expressed as absorbance per gram NDF. Colorimetric determination of condensed tannins (TC) was done according to the HCl-Fe^{3+} method of Porter et al. [1986] assuming an effective $E^{1\%,\ 1\ cm,\ 550\ nm}$ of leucocyanidin of 460 using the formula:

$$E^{1\%}_{1cm} = \frac{A}{cb}$$

where c = concentration in grams per 100 ml,
b = path length through the sample in centimetres,
A = absorbance at 550 nm.

Data and statistical analysis

Live weight gain (LWG) over the experimental period was calculated by regressing body weight (kg) of individual animals measured at 2-week intervals on time (in days). Residual DM at the various stages of incubation were expressed as fractions of original amounts incubated and the results analysed by non-linear regression (SAS 1987) based on the following model (Robinson et al., 1986):

$$R_t = U + (1000 - S - U) * e^{-kd(t-L)}$$

Where R_t = residue at time t
U = truly indigestible residue (336 h incubation)
S = water soluble fraction (0 h incubation)
Kd = rate of degradation (% / h)
L = lag phase.

Different rates of degradation were obtained by fitting the model with (Kd1) and without (kd2) lag phase, while kd3 was obtained by regressing R_t with time after natural logarithm transformation of R_t. The proportion DM escaping rumen degradation (EDM) was calculated from the equation:

$$EDM = U + D\left(\frac{kp}{kp + kd2}\right)$$

where kp = the passage rate (assumed 4.5% per hour [Lechner-Doll et al., 1990])
U = DM residue after 336 h incubation and
D = water insoluble degradable fraction (1-S-U).

Dry matter degradability parameters, LWG, intake and in-vivo digestibility coefficients were subjected to analysis of variance (ANOVA) using the general linear model procedure (GLM) available in SAS [1987]. Correlation analyses were used to establish the relationship between tannin levels and other chemical composition attributes.

Results

Chemical composition of teff straw and browse leaves are presented in Table 1. Teff straw used as the basal diet was a characteristic low quality forage as shown by the low CP and high NDF. Lablab had higher NDF and ADF and lower CP content than the browses. The CP content of browses ranged from 202 to 279 g kg^{-1} of DM and was highest for S2024. Different levels of tannins were detected using the various methods (TP, AP, PA and TC). A positive correlation was observed between PA and TC (r=0.90 P<0.001), lignin and PA (r=0.79, P<0.01), and lignin and TC (r=0.86, P<0.001). TP and AP were not significantly (P>0.05) correlated to any of the chemical composition attributes determined. The tannin levels (TC and PA) were highest in goetzei, S2024, S15036 and leucaena, intermediate in S15019, S10865, S1198 and S1190, and lowest in tagasaste and lablab.

Table 1. The dry matter (g kg^{-1}) and nutrient composition (g kg^{-1} DM) of the feed ingredients.

	DM	Ash*	CP*	NDF*	ADF*	Lignin*	TP*	AP*	PA	TC*
Dolichos lablab	905	43	153	387	335	56	10	55	2.5	0.8
Chamaecytisus palmensis	908	112	202	343	231	67	22	135	7.4	1.2
Leucaena leucocephala	905	107	266	208	178	81	58	131	35.1	22.2
Sesbania sesban-1190	905	66	239	140	131	29	11	62	16.4	2.2
Sesbania sesban-1198	906	73	267	144	123	28	59	97	23.1	2.3
Sesbania sesban-10865	902	89	239	125	106	29	33	163	6.6	2.5
Sesbania sesban-15019	906	110	209	162	157	49	21	100	30.5	9.2
Sesbania sesban-15036	910	73	208	153	193	74	18	179	71.9	15.8
Sesbania sesban-2024	903	113	279	146	196	83	3	132	71.8	22.6
Sesbania goetzei	902	118	204	223	288	114	57	57	103.4	29.3
Teff straw	920	100	38	648	460	41	ND	ND	ND	ND

DM: dry matter; * expressed in DM basis CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre; TP: total phenolics (g kg^{-1} DM); AP: acetone-soluble phenolics (g kg^{-1} DM); PA: fibre bound proanthocyanidins (550 nm OD per g NDF); TC: Total soluble proanthocyanidins (g kg^{-1} DM); ND: not determined.

Table 2 shows the comparison of dry matter degradability characteristics of the forages. Lablab had lower water solubility (S) and higher (P<0.05) truly undegradable DM (U) than the other browse supplements. With increasing tannin levels (among Sesbania accessions), there was significant decrease (P<0.05) in rate of degradation (kd). The estimated kd increased in the order kd2 >kd1> kd3. Increasing levels of tannin was also associated with a general increase in escape DM.

Table 2. Variation in DM degradation characteristics and estimated escape DM (g kg^{-1} DM) of teff straw and forage legumes.

Sample	S	U	L	kd1	kd2	kd3	escape DM
Teff straw	97	201	-2.50	1.34	1.30	0.77	743
Dolichos lablab	291	211	-2.88	4.04	3.71	0.75	473
Chamaecytisus palmensis	349	135	0.70	4.32	4.53	1.12	398
Leucaena leucocephala	396	146	-0.05	2.45	2.49	0.97	442
Sesbania sesban-1190	356	61	1.45	7.07	8.42	1.53	288
Sesbania sesban - 1198	342	76	2.42	5.72	7.42	1.58	332
Sesbania sesban-10865	396	61	0.82	3.34	3.56	1.53	372
Sesbania sesban-15019	358	85	1.03	4.73	5.12	1.39	357
Sesbania sesban-15036	334	67	1.98	3.88	4.54	1.59	395
Sesbania sesban-2024	345	81	2.40	4.97	6.31	1.64	354
Sesbania goetzei	309	145	1.18	3.03	3.30	1.06	501
SED (n=3)	4.9	8.0	1.63	0.67	0.88	0.08	

SED: standard error of difference ; S: water soluble fraction (g kg^{-1}DM); U: truly undegradable (g kg^{-1}DM); L: lag phase (h); kd1: rate of degradation (%/h) from nonlinear regression excluding lag phase; kd2 : rate of degradation (%/h) from nonlinear regression with a lag phase; kd3 : rate of degradation (%/h) from linear regression after logarithm transformation.

The feed intake of forages and live weight gains (LWG) of sheep are given in Table 3. There was no significant ($P>0.05$) effect on teff straw intake when teff straw was supplemented with the forage legumes. However, animals supplemented with low-tannin forage legumes such as lablab, S1190, S1198, and S10865, tended to have a lower teff straw intake than those fed teff straw alone. The converse was true for those fed high tannin supplements such as S15019, S15036, S2024 and goetzei. Supplementation significantly increased ($P<0.05$) total DM intake, OM intake and LWG. No significant ($P>0.05$) difference was observed among the supplements. The animals fed the control diet lost weight (-17.5 g per day) while the supplemented ones gained weight in the range of 28.9 - 43.8 g per day. Sheep supplemented with leucaena had a higher ($P<0.05$) LWG than those supplemented with lablab, S1190 and goetzei. No significant ($P<0.05$) difference in LWG was observed among the Sesbania accessions. However with increasing tannin levels (among *Sesbania* accessions), there was an increase (S1190 <S1198 <S10865 <S15019) followed by a decrease (S2024 >S15036 >goetzei) in LWG.

Voluntary intake and digestibility values from the metabolism trial are given in Table 4. There was no significant ($P>0.05$) effect of supplementation on teff straw intake. The supplemented animals had significantly higher ($P<0.05$) total DM, OM and CP intake than those fed teff straw alone. The digestibilities of total DM, OM and supplement

Table 3. Feed intake and growth rate of sheep fed teff straw (g/d) alone or supplemented with browses having varying tannin levels.

Diet	Teff	Supp	DMI	DMI ($g/kgW^{0.75}$)	OMI	DOM above maintenance	WO	LWG	LWG ($g/kgW^{0.75}$)
Teff straw	535	0	536	58.6	495	4.1	19.9	-17.5	-1.9
Teff + *D. lablab*	515	183	698	69.9	640	9.3	20.2	28.9	2.9
Teff + *C. palmensis*	541	181	722	71.2	673	9.3	20.3	36.4	3.6
Teff + *L. leucocephala*	521	181	703	71.0	648	10.6	19.3	43.8	4.4
Teff + *S. sesban*-1190	494	180	673	70.8	616	11.5	18.7	31.4	3.3
Teff + *S. sesban*-1198	517	177	692	71.0	635	9.2	19.3	33.8	3.5
Teff + *S. sesban*-10865	530	177	707	70.9	647	9.3	19.9	34.5	3.5
Teff + *S. sesban*-15019	559	183	742	74.3	679	9.7	19.7	39.9	4.0
Teff + *S. sesbania*-15036	548	183	731	75.1	670	12.1	19.3	33.3	3.4
Teff + *S. sesbania*-2024	555	183	738	75.7	679	14.0	19.2	36.5	3.7
Teff + *S. goetzei*	563	182	745	77.0	688	13.5	19.2	31.3	3.2
SED (n=6)	31.2	-	32.3		29.8		1.12	5.86	

Supp: supplement (g/d); DMI: dry matter intake (g/d); OMI: organic matter intake (g/d); W: body weight of the animals ; WO: initial body weight (kg); LWG: live weight gain (g/d); DOM: digestible organic matter ($g/kgW^{0.75}$) assuming 26 g DOM/$kgW^{0.75}$ for maintenance [ARC, 1980].

Table 4. Effect of supplementing teff straw with forage legumes leaves on intake and digestibility in Ethiopian highland sheep (metabolism study).

Diet	Teff straw	Teff straw supplemented with										SED	Sig.
		Lab	Tag	Leu	S1190	S1198	S10865	S15019	S15036	S2024	Goe		
Intake (g DM day^{-1})													
Teff straw	520	517	538	545	499	543	531	566	559	546	569	30.5	NS
Supplement	0	185	184	183	183	183	182	183	183	183	182	-	-
Total	520	702	723	728	682	726	713	749	742	729	751	30.5	***
OM	480	644	674	671	624	666	653	685	680	672	694	28.2	***
DOM	267	354	377	357	361	360	355	360	377	386	385		
Total N	3.2	7.7	9.2	11.1	10.1	11.1	10.2	9.6	9.5	11.5	9.4	0.19	***
CP (g kg^{-1} DM)	38.4	68.5	78.5	95.3	92.6	95.6	89.4	80.1	80.0	98.6	78.2		
Digestibility (g kg^{-1})													
DM	522	520	505	530	551	510	513	492	502	544	514	25.7	NS
Supplement DM[$]	-	514	454	550	618	476	488	403	438	606	484	87.7	NS
OM	556	550	532	559	579	540	544	525	554	575	555	25.7	NS
NDF	573	558	514	557	553	524	520	508	509	527	504	30.1	***
Supplement NDF[$]	-	513	2	50	33	-4	-19	-22	-27	-3	-8		

Lab: *Dolichos lablab*, Tag: *Chamaecytisus palmensis*, Leu: *Leucaena leucocephala*, *Goe: Sesbania goetzei* and six accessions of *Sesbania sesban* (S1190, S1198, S2024, S10865, S15019 and S15036); CP: crude protein; OM: organic matter; DOM: digestible organic matter; NS: P>0.05; *:P<0.05; *** P<0.0001; SED based on n=6; [$] :supplement digestibility was determined by digestibility by difference method.

were similar (P<0.05) among the diets. The digestibility of NDF decreased significantly (P<0.05) with supplementation. The control diet had significantly higher (P<0.05) NDF digestibility than diets supplemented with leucaena, S10865, S15019, S15036 and S2024.

Discussion

The value of forages as supplements depends mainly on their capacity to provide the nutrients that are deficient in the basal diet. This includes their ability to provide the essential nutrients to the rumen microbial population and/or critical nutrients to meet the host animal's requirements thus increasing the efficiency of feed utilization [Elliot and McMeniman, 1987]. Thus teff straw alone supplied a deficient diet which responded to supplementation with forage legumes irrespective of the tannin level, probably as a consequence improved N supply in the rumen since the consumed supplemented diets contained 6.9 to 9.6% CP.

Recommended use of tanniferous forages is complicated by the effects of the stage of maturity, local environment [Barry and Forss, 1983] and drying procedures [Price et al., 1979] on the phenolic content. Isolation and quantification of phenolics in plants are essential to studies on their nutritional and ecological effects [Waterman and Mole, 1994], although the commonly used colorimetric assays have many problems [Martin and Martin, 1982]. However, there are a growing number of methods for assaying tannins in plants [Waterman and Mole, 1994]. A considerable variation in the level of phenolics was observed in this study, which depended not only on legume species, but also on the method of analysis. However, no single method will give results that are satisfactory in relation to nutritional effects because the chemical properties that are involved in the reactivity of polyphenols in colorimetric and/or precipitation assays may differ from the properties that underlie their nutritional or toxic effect [Reed, 1995]. There were however, some reasonable correlations among the methods which emphasises their relative tannin estimation rather than their quantitative significance.

Forages endowed with condensed tannins known to depress nutritive value, such as sericea lespedeza [*Lespedeza cuneata*; Terrill et al., 1989] or mulga [*Acacia aneura*; Pritchard et al., 1988] may have a negative impact on animal performance even if these species represent only a small proportion of the diet. A primary manifestation of adverse effect is depressed intake of metabolizable energy which occurs principally due to a reduced voluntary dry matter intake as a consequence of impaired rumen fermentation of cellulose and hemicellulose [Barry and Duncan, 1984]. While animals loose weight, as it has been observed when sheep were fed *Acacia aneura* [Pritchard et al., 1988] or dried *Calliandra* leaves [R.J. Kaitho, unpub.], all the animals supplemented with the tannin-rich forages in this study gained daily at least 2.9 g/kg$W^{0.75}$. The LWG was even

higher in leucaena with higher level of tannins than lablab, tagasaste, S1190, S1198, S10865 and S15019 supplemented animals. These anomalies could arise due to the differences in the chemical, biochemical nature, variation in molecular weight and nature of interflavonoid linkage of tannins [Kumar, 1983; Hagerman et al., 1992].

The variation in anti-nutritional effects of tannins in different species of animals may arise due to the ability of certain animals to secrete trichloroacetic acid soluble proline-rich protein. These proteins may constitute the first line of defence against ingested tannins [Mehanso et al., 1987]. Under grazing conditions, animals have the advantage of selecting from a wide range of browses with different levels of anti-nutritional factors, thus obtaining a high-quality feed. Consumption of various types of forages reduces chances of poisoning [Dicko and Sikena, 1992]. Le Houérou [1991] reported that consumption of mixed shrubs was higher than of a single species. An extensive review of the role of plant tannins on forage quality led McLeod [1974] to conclude that these polyphenolic compounds exert no detrimental effects on the grazing ruminant.

The significance and defence phenomenon of tannins in browse is poorly understood. In this study we have observed (among *Sesbania* accessions) an increase (S1190< S1198< S10865< S15019) followed by a decrease (S2024>S15036> goetzei) in LWG with increasing tannin levels. Certainly, low concentrations of condensed tannins are beneficial while high concentrations can be detrimental. Despite the positive response of sheep in terms of DM, digestible organic matter intake and increased growth, the role of these legumes as supplements in the strict sense, remains open to debate. One hypothesis was that legume feeding would increase the intake and the digestibility of fibre, thereby improving the efficiency of use of the basal component of the diet (teff straw). The NDF digestibility was significantly ($P<0.05$) depressed by supplementation and calculated supplement NDF digestibility was very low and in most cases negative (Table 4). However, there is a problem in interpreting NDF digestibility in this case, because condensed tannins complex with other dietary components and appear as faecal NDF, which biases the estimation of true-NDF digestibility [Reed, 1986]. Proanthocyanidins could also depress digestibility by inhibiting microbial enzymes [Waage et al., 1984] and by forming indigestible complexes with protein and carbohydrates [Hagerman, 1989].

Although it is difficult to predict the effects of low concentration of condensed tannins on the nutritive value of mixed forages [Waghorn et al., 1987], results from this study indicate that, with increasing condensed tannin concentration (S1190< S1198< S10865< goetzei) the rate of degradation (kd2) decreased (8.42-3.30 $\%h^{-1}$), while the estimated DM escaping rumen degradation increased (288-501 g kg^{-1} DM). Condensed tannins protect protein and fermentable carbohydrates against ruminal fermentation and consequently increase the supply of high-quality nutrients entering the duodenum [Mangan, 1988]. The S1190 and S1198 were rapidly degraded in the rumen, providing

high levels of rumen ammonia, much of which could be wasted by excretion as urinary urea. Species which contain moderate levels of tannins will therefore provide adequate levels of both rumen degradable protein and non-degradable rumen protein, and will therefore be more effective sources of supplemental protein for ruminants [Kaitho et al., 1997]

Supplementation with lablab, leucaena, S1190, S1198 and S10865 depressed the intake of teff straw while the converse was true for tagasaste, S15019, S2024, S15036 and goetzei, although the trends were not significant ($P<0.09$). A significant ($P<0.05$) increase in the total DM intake and LWG was observed when the teff straw was supplemented with the browses. These results were consistent with those of Van Eys et al. [1986] and Ash [1990] respectively. Van Eys et al. [1986] supplemented Napier grass with *Sesbania* and *Gliricidia* and found no effect on intake, although weight gain was improved. However, the Napier grass in that experiment contained more N (1.90 vs. 0.61%) than teff straw in the present study. Supplementation with legumes is usually most effective when fed with roughages containing <20 g N kg^{-1} digestible organic matter, because they increase the rumen ammonia concentration by providing ruminally fermentable N [Egan, 1986].

Conclusion

The principal finding of this study was that it is not the levels of condensed tannins in a particular browse species *per se* that determine animal performance but may be reactivities. Results from this study indicate that increasing tannin content is beneficial up to an optimum level (which varies between plant species), upon which when exceeded animal performance is severely affected. Manifestation of adverse effects depends on the level of intake of the browse, and on the extent and rate of ruminal metabolism of the anti-nutritive constituents. However, condensed tannins confer important advantages in ruminant nutrition with respect to the prevention of excessive degradation of protein in the rumen.

Acknowledgements

The authors wish to express their appreciation to the staff of ILRI Debre Zeit station for personnel and material support, and B.A. Williams for critically reading the manuscript.

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Chapter 7

Utilization by sheep of browse supplements with varying tannin levels: 2. nitrogen metabolism

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Utilization by sheep of browse supplements with varying tannin levels: 2. nitrogen metabolism

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Abstract

The effect of different levels of tannins in browse supplements on protein metabolism was investigated using sixty-six male Ethiopian Menz sheep in a 90-day trial. Teff straw (*Eragrostis tef*) was fed ad-libitum (control diet), or supplemented with 190 g dried leaves of lablab (*Dolichos lablab*), tagasaste (*Chamaecytisus palmensis*), leucaena (*Leucaena leucocephala*), goetzei *(Sesbania goetzei),* and six accessions of *Sesbania sesban* (S1190, S1198, S2024, S10865, S15019 and S15036), in a completely randomized block design. The supplemented animals had significantly ($P<0.05$) higher total dry matter (DM) and nitrogen (N) intake than the ones fed teff straw alone. The digestibility of N was lower for the control diet than for any other treatment ($P<0.05$). S1190 and S1198 supplemented diets had significantly higher ($P<0.05$) N digestibilities than all other diets. Faecal N, urinary N and urinary N per kg N excreted were significantly different ($P<0.0001$) among diets. With increasing tannin levels (among *Sesbania* accessions) there was a significant decrease ($P<0.05$) in urinary N (S1190 >S1198 >S10865 >S15019 >S15036), and an increase ($P<0.05$) in faecal N (S1190 <S1198 <S10865 <S15019 <S15036). Supplementation increased faecal N output significantly ($P<0.0001$) as well as the N retention. Among the forage supplements, N retention was significantly ($P<0.0001$) lower for lablab, tagasaste, leucaena, S15019 and goetzei supplemented diets, than for S1190, S1198, S15036 and S2024. Apparent nitrogen digestibility (ND) was positively correlated ($P<0.001$) to the supplement DM and crude protein (CP) degradation after 24 h ($r=0.93$ and $r=0.85$, respectively), the CP content ($r=0.87$), and negatively correlated to ADFand NDF ($r=-0.87$ and -0.87, respectively). The CP degradability characteristics of the forages differed ($P<0.001$) in water solubility (93-470 g kg^{-1} N), rate of degradation (2.58-9.73 %/h), lag phase (-1.36-13.37 h), and estimated escape protein (262-619 g kg^{-1} N). With increasing tannin levels (among *Sesbania* accessions), there was a significant decrease ($P<0.0001$) in the rate of degradation (S1190> S1198>S10865> S15019> S15036), and an increase in the estimated escape nitrogen. The estimated rumen degradable protein (supplements) varried from 482 to 744 g kg^{-1} protein, while intestine digestible protein and the undegradable protein varied from 140 to 314 g kg^{-1} protein, hence the browses can supply adequate levels of rumen degradable and bypass protein.

Key words: Browse, nitrogen, intake, digestibility, degradability, retention

Introduction

Deficiencies of nutrients in the diets of ruminants fed low quality roughages (e.g. tropical pastures in the dry season, or cereal crop residues) constrain animal growth. Most of these deficiencies can be corrected by supplementation. Low level supplementation of tropical grass based diets with browses has improved animal productivity [Ash, 1990]. The proteins are digested in the rumen to provide ammonia and amino acids for microbial protein synthesis. Microbial cells then pass to the small intestine, providing the major source of absorbed amino acids for the ruminant. The positive responses obtained have been attributed to the abilities of the legume forages to overcome the depressing effect of low nitrogen (N) concentration of grass, on intake [Minson and Milford, 1967], and to provide ruminally degradable N [Van Eys et al., 1986] or estimated escape protein [Flores et al., 1979].

Browse species of tropical legumes are associated with anti-nutritional factors or 'deleterious substances' in livestock nutrition, which act via direct toxicity, through reduced palatability [Skerman et al., 1988], and/or a reduced digestibility of the feed [Barry and Manley, 1984; Reed and Soller, 1987; Robbins et al., 1987]. Although much still needs to be elucidated, particularly with regard to the components causing reduced palatability, the anti-nutritional factors implicated thus far include polyphenolics, cyanogens, saponins, non-protein amino acids, phytohaemagglutinins (lectins), alkaloids, triterpenes and oxalic acids [Kumar, 1992; Kumar and D'Mello, 1995]. There are about 8,000 polyphenols, 270 non-protein amino acids, 32 cyanogens, 10,000 alkaloids and several saponins which occur in various plant species [Kumar, 1992] among which polyphenolics make the largest contribution. Tannins are broadly defined as any phenolic compound of sufficiently high molecular weight with sufficient phenolic hydroxyls and other suitable groups (i.e. carboxyls), to form strong complexes with protein and other macro-molecules under the particular environmental conditions being studied [Horvath, 1981]. Hydrolyzable tannins and condensed tannins (proanthocyanidins), are the two groups of these compounds which may be differentiated by their structure and reactivity towards hydrolytic reagents. Proanthocyanidins (PA) can react by hydrogen bonding with plant protein in the near neutral pH range to form PA-protein complexes, which are stable and insoluble at pH 3.5-7.0, but dissociate and release protein at pH <3.5 [Jones and Mangan, 1977]. Thus PA found in many browses form complexes with plant proteins which decreases their rate of digestion (degradability) in the rumen, thereby decreasing rumen ammonia concentrations and increasing the amount of plant protein by-passing the rumen. When the tannin-protein complexes are dissociated in low pH (abomasum), an additional source of protein becomes available for absorption by the animal. Occasionally, the tannin-protein complexes don't dissociate fully. A considerable variation exists among

browse species and members of the same species in their propensity to elicit these effects. Therefore, the objectives of this study were to compare browse leaves with varying tannin levels, as protein supplements for growing sheep, and to determine the relationship between the intake of tannins and parameters of protein digestion.

Materials and methods

The study was conducted at the International Livestock Research Institute (ILRI) research farm at Debre Zeit, Ethiopia. Air-dried leaves of lablab (*Dolichos lablab*), tagasaste (*Chamaecytisus palmensis*), leucaena (*Leucaena leucocephala*), goetzei *(Sesbania goetzei)* and six accessions of *Sesbania sesban* (S1190, S1198, S2024, S10865, S15019 and S15036), were supplements to sheep fed teff straw (*Eragrostis tef)*.

Sixty-six male Ethiopian Menz sheep (19.4 kg ; SD=1.81; average age of 14 months) bought from nearby markets were blocked on live weight and randomly assigned within blocks to 11 treatments in a completely randomized block design. Unchopped teff straw (*Eragrostis tef*) was given ad-libitum (i.e. about 1.5 times the previous day's intake) either alone (control diet), or supplemented with 190 g dried forage. No mineral lick was offered but all the sheep had access to water ad-libitum. The feeding, sampling and digestibility trial was done as described by Kaitho et al. [1997]. The sheep were weighed fortnightly.

Thirty-three male Ethiopian Menz sheep (25.4 kg; SD=1.12; average age of 20 months), with rumen fistulae were used in the nitrogen degradability trial. The experimental design and other details were as described by Kaitho et al. [1997]. Air-dried samples were milled (2.5 mm screen), and about 2.5 g weighed per nylon bag (14 cm x 8 cm, 41μm pore size, Polymon, Switzerland), and incubated for 0, 3, 6, 12, 24, 48, 72, 96, 120 and 336 h. After incubation, the bags were washed using a non-automatic washing machine (Tefal alternatic, Finland). The water was changed five times, with each cycle lasting for 5 minutes. The bags were dried in a forced-air oven at 60°C for 48 h, cooled in a desiccator and weighed.

Chemical analysis

Samples of feeds and refusals were ground to pass a 1-mm screen using a Wiley mill, while frozen faecal samples and rumen incubated residues were ground with a mortar and pestle. Dry matter and ash was assayed on the offered and refused feed and faeces, using the method described by the AOAC [1990]. All other analyses were determined using air-dried feed samples, frozen faecal samples and oven-dried (60°C) rumen-incubated residues. Kjeldahl nitrogen (N) analysis in forages, faeces, urine and

rumen-incubated residues were performed according to AOAC [1990] standard procedures. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin, were analysed using the method of Van Soest and Robertson [1985].Total water-soluble phenolics (TP) were determined using Folin-Denis reagent and sodium carbonate [Kaitho et al., 1993]. Neutral-detergent insoluble proanthocyanidins (PA) were determined using the method of Reed et al. [1982]. Colorimetric determination of condensed tannins (TC) was done according to the method of Porter et al. [1986] as already described by Kaitho et al. [1997]. Saponin levels were estimated by preparing extracts of the leaf samples in water. After shaking, persistent foam on the liquid surface was used to rank the feeds.

Data and statistical analysis

Average daily growth over the experimental period was calculated by regressing body weight (kg) of individual animals measured at 2-week intervals with time (in days). Residual CP at the various stages of incubation were expressed as fractions of original amounts incubated and the results analysed by non-linear regression [SAS, 1987] as described by Robinson et al. [1986].

$$R_t = U + (1 - S - U) * e^{-kd(t-L)}$$

Where R_t = residue at time t
U = truly indigestible residue (336 h incubation)
S = water soluble fraction (0 h incubation)
Kd = rate of degradation (% / h)
L = lag phase.

Different rates of CP degradation were obtained by fitting the model with (Kd1) and without (kd2) lag phase, while kd3 was obtained by regressing R_t with time after logarithm transformation. The proportion escaping rumen degradation (ECP) was calculated from the equation:

$$ECP = U + D\left(\frac{kp}{kp + kd2}\right)$$

where kp = the passage rate (kp) of 4.5 % per hour
D = the potentially degradable proportion (1-S-U).
Rumen degradable protein (RDP) was calculated as:

$$RDP = S + D(\frac{kd2}{kp + kd2})$$

Similarly, intestinal digestible protein (IDP) was estimated as:

$$IDP = D(\frac{kp}{kp + kd2})$$

Microbial protein (MP) was estimated as:

$$MP = 0.15 * 0.65 * DOM$$

where DOM = digestible organic matter.
True digestibility of CP was estimated by assuming 50 g endogenous protein per kg feacal dry matter and true digestibility of 85% for MP. Intake and in-vivo digestibility coefficients were subjected to analysis of the variance (ANOVA) using the general linear model procedure (GLM) available in SAS [1987]. Correlation analysis was used to establish the relationships between in vivo digestibility, degradability and chemical composition attributes.

Results

The CP content (g kg^{-1} DM) of the forages was highest in S2024 (279) followed in decreasing order by S1198 (267), leucaena (266), S1190 (239), S10865 (239), S15019 (209), S15036 (208), goetzei (204), tagasaste (202), lablab (153) and teff straw (38) (Table 1). The saponins were highest in S1190, S1198, S10865, S15019 and S2024; medium in S15036 and goetzei; and lowest in lablab and tagasaste. They were not detected in leucaena and teff straw. Different levels of tannins were detected using the various methods (TP, PA and TC). The tannin levels (TC and PA) were highest in goetzei, S2024, S15036 and leucaena; intermediate in S15019, S10865, S1198 and S1190; and lowest in tagasaste and lablab. *Sesbania sesban* 2024 had the highest tannin level among the *S. sesban* accessions, and differed ($P<0.05$) significantly from the other *S. sesban* accessions relative to its tannin level. The NDF and ADF differed appreciably with the mean values varying from 125 to 648 g kg^{-1} DM and 106 to 460 g kg^{-1} DM for NDF and ADF, respectively (Table 1). There was a tendency for NDF and ADF to be inversely related to CP, however ADF was higher than NDF in both S15036 and S2024. The nitrogen bound to NDF was highest in leucaena while lower and less variable among *Sesbania* accessions.

Table 1. The dry matter (g kg^{-1}) and nutrient composition (g kg^{-1} DM) of the feed ingredients.

	DM	ASH	CP	NDF	NDFN	NDFCP (%CP)	ADF	Lignin	TP	PA	TC	Saponin
D. lablab	905	43	153	387	14	22..1	335	56	10	2.45	0.8	*
C. palmensis	908	112	202	343	31	32..9	231	67	22	7.40	1.2	*
L. Leucocephala	905	107	266	208	44	21.5	178	81	58	35.06	22.2	ndd
S. sesban-1190	905	66	239	140	30	11.0	131	29	11	16.44	2.2	***
S. sesban-1198	906	73	267	144	31	10.4	123	28	59	23.08	2.3	***
sesban-10865	902	89	239	125	34	11.0	106	29	33	6.61	2.5	***
S. sesban-15019	906	110	209	162	34	16.5	157	49	21	30.47	9.2	***
S. sesban-15036	910	73	208	153	34	15.6	193	74	18	71.89	15.8	**
S. sesban-2024	903	113	279	146	29	9.5	196	83	3	71.76	32.6	***
S. goetzei	902	118	204	223	19	13.0	288	114	57	103.40	29.3	**
Teff straw	920	100	38	648	3	32..0	460	41	nd	nd	nd	ndd

DM: dry matter; CP: crude protein; NDF: neutral detergent fibre; NDFN: neutral detergent fibre bound nitrogen (g kg^{-1} NDF); NDFCP: NDF bound CP (% CP); ADF: acid detergent fibre ; TP: total phenolics (g kg^{-1} DM); PA: fibre bound proanthocyanidins (550nm OD per g NDF); TC: Total soluble proanthocyanidins (g kg^{-1} DM). Saponin content : *<**<***; nd: not determined; ndd: not detected.

Table 2. Variation in Crude protein degradation characteristics and estimated by-pass protein (g kg^{-1} DM) of teff straw and forage legumes.

Ingredient	S	U	L	kd1	kd2	kd3	BP	RDP	IDP
Teff straw	12	18	13.37	1.92	2.58	0.47	24	12	19
Dolichos lablab	44	27	-1.1	11.55	10.2	1.21	50	99	21
Chamacytisus palmensis	43	13	1.03	5.23	5.71	1.95	80	126	48
Leucaena leucocephala	125	28	3.8	2.91	3.5	1.53	97	153	74
Sesbania sesban-1190	65	7	0.65	8.93	9.73	2.3	63	178	47
Sesbania sesban - 1198	66	15	1.46	7.01	8.25	2.56	88	186	61
Sesbania sesban-10865	76	7	-0.88	5.77	5.34	2.42	76	168	57
Sesbania sesban-15019	45	10	-1.36	6.01	5.34	1.97	76	141	50
Sesbania sesban-15036	19	12	1.17	4.22	4.62	1.93	104	129	65
Sesbania sesban-2024	72	12	2.06	5.44	6.73	2.42	100	184	73
Sesbania goetzei	62	18	2.09	2.54	2.81	1.22	103	98	76
SED (n=3)	31.9	6.8	8.0	0.66	0.61	0.98	0.08		

SED: standard error of difference ; S: water soluble fraction (g kg^{-1} DM); U: truly undegradable protein (g kg^{-1} DM); L: lag phase (h); kd1: rate of degradation (%/h) from nonlinear regression excluding lag phase; kd2 : rate of degradation (%/h) from nonlinear regression with a lag phase; kd3 : rate of degradation (%/h) from linear regression after logarithm transformation; BP: by-pass protein (g kg^{-1} DM); RDP: rumen degradable protein (g kg^{-1} DM); IDP: intestine digestible protein (g kg^{-1} DM).

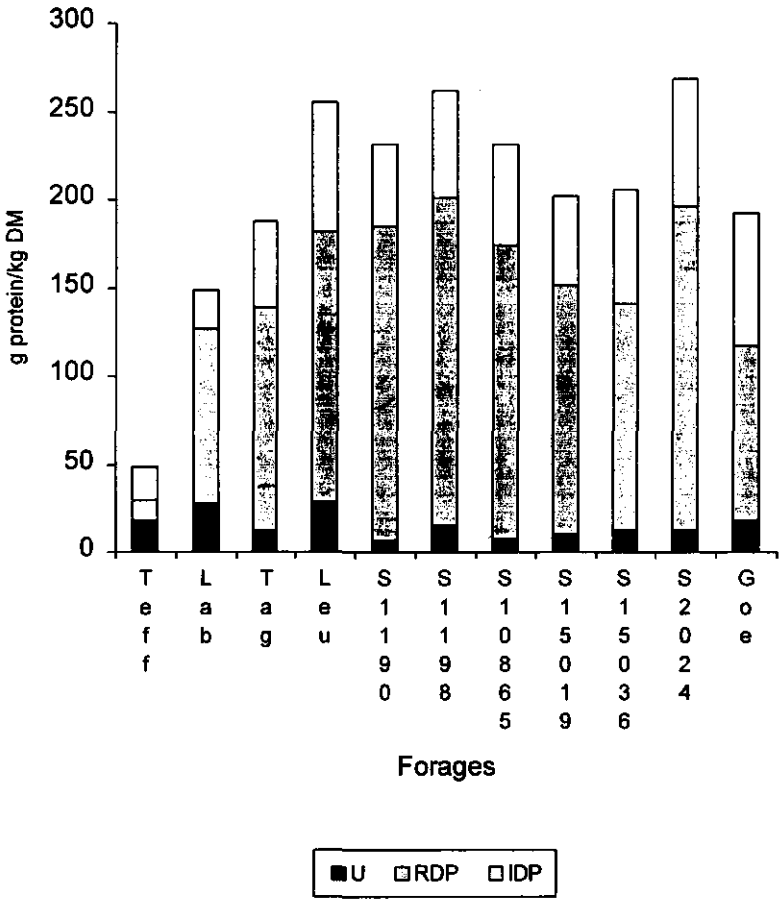

Figure 1. Proportions of truly undegradable crude protein (U), rumen degradable protein (RDP) and intestine digestible protein(IDP) of teff straw and browse supplements (use Table 3 to identify the forages).

Table 2 shows a comparison of the crude protein degradability characteristics of the forages. The forages differed ($P<0.001$) in water solubility (12-125 g kg^{-1} DM), rate of degradation (2.58-10.20 %/h), lag phase (-1.36-13.37 h), and estimated by-pass protein (24-104 g kg^{-1} DM). With increasing tannin levels (among *Sesbania* accessions), there was a significant decrease ($P<0.0001$) in the rate of degradation (S1190> S1198> S10865> S15019> S15036), and an increase in the estimated by-pass protein. The RDP was relatively higher than IDP and U (Figure 1). This indicates that most of the nitrogen in the browses was either rumen degradable or has the potential to be digested in the small intestine.

Table 3. Effect of supplementing teff straw with forage legumes leaves on digestibility, excretion and retention of sheep (metabolism study).

Diet	Teff straw	Teff straw supplemented with											
		Lab	Tag	Leu	S1190	S1198	S10865	S15019	S15036	S2024	Goe	SED	Sig.
Intake (g DM day^{-1})													
Teff straw	520	517	538	545	499	543	531	566	559	546	569	30.5	NS
Supplement	0	185	184	183	183	183	182	183	183	183	182	-	-
Total	520	702	723	728	682	726	713	749	742	729	751	30.5	***
DOM	267	354	377	357	361	360	355	360	377	386	385		
N	3.2	7.7	9.2	11.1	10.1	11.1	10.2	9.6	9.5	11.5	9.4	0.19	***
MP (g day^{-1})	26.2	34.5	36.6	34.8	35.0	35.1	34.7	35.1	36.7	37.6	37.5	1.99	***
Digestibility (g kg^{-1})													
DM	522	520	530	505	551	510	513	492	502	544	514	25.7	NS
N	232	465	444	472	609	604	538	458	500	556	429	64.9	***
TCP	997	893	806	785	911	913	865	836	872	843	809	61.8	*
LWG (g day^{-1})	-17.5	28.9	36.4	43.9	31.4	33.8	34.5	39.9	33.3	36.5	31.3		
N excretion													
Faecal N (g day^{-1})	2.5	4.1	5.1	5.9	3.9	4.4	4.7	5.2	4.8	5.1	5.4	0.46	***
Urinary N (g day^{-1})	0.4	1.7	1.9	3.4	2.8	3.0	2.6	2.1	1.6	2.5	2.2	0.35	***
Urinary N per kg N excreted	161	293	264	359	408	405	353	291	250	323	291	33.1	***
N retention (g day^{-1})													
N retention	0.3	1.9	2.2	1.9	3.4	3.7	2.9	2.3	3.2	3.9	1.9	0.62	***
g per kg N intake	95	245	243	167	335	332	285	332	330	339	200	74.9	*
g per kg N digested	680	526	541	339	542	547	516	483	660	605	364	165.2	NS
g CP per g LWG	-0.11	0.41	0.38	0.27	0.68	0.68	0.53	0.36	0.60	0.67	0.38		

Lab: *Dolichos lablab*, Tag: *Chamaecytisus palmensis*, Leu: *Leucaena leucocephala*, *Goe: Sesbania goetzei* and six accessions of *Sesbania sesban* (S1190, S1198, S2024, S10865, S15019 and S15036); NS: P>0.05; *:P<0.05; *** P<0.0001; SED based on n=6; LWG: live weight gain (g day^{-1}), TCP: true digestibility of crude protein.

Table 4. Correlation coefficients between digestibility and chemical composition and ruminal degradation characteristics.

Parameters	DMD	ND	D24	kd1	N24	CP	NDF	ADF	Lignin	TP	PA	TC
DMD	1.00	0.22	0.18	0.30	0.25	0.05	0.10	0.08	-0.09	-0.51	-0.10	-0.15
ND		1.00	0.93_a	0.53	0.85_b	0.87_b	-0.87_b	-0.87_b	-0.21	-0.13	-0.22	-0.34
D24			1.00	0.54	0.90_b	0.83_c	-0.85_b	-0.89_b	-0.23	-0.38	-0.36	-0.50
kd1				1.00	0.78_c	0.17	-0.19	-0.25	-0.49	-0.52	-0.68_d	-0.75_d
D24					1.00	0.68_d	-0.65_d	-0.76_c	-0.43	-0.40	-0.77_c	-0.75_d
CP						1.00	-0.92_a	-0.89_b	0.12	0.27	0.15	0.27
NDF							1.00	0.93_a	-0.04	-0.13	-0.29	-0.22
ADF								1.00	0.24	-0.12	0.25	0.25
LIGNIN									1.00	0.18	0.79_c	0.86_b
TP										1.00	0.19	0.30
PA											1.00	0.90_b
TC												1.00

subscripts a, b, c , d: level of significance for 0.0001, 0.001, 0.01 and 0.05 probability, respectively; DMD and ND: in-vivo dry matter and nitrogen digestibility; D24 and N24 : dry matter and nitrogen degradation after 24 hours; kd1: rate of degradation; NDF: neutral detergent fibre; ADF: acid detergent fibre; TP: total phenolics; PA: fibre bound proanthocyanidins; TC: Total soluble proanthocyanidins.

Voluntary intake, digestibility, N excretion and N retention values during the metabolism trial are given in Table 3. The supplemented animals had significantly ($P<0.05$) higher total DM and N intake, than the ones fed teff straw only. Dry matter digestibility was not significantly different ($P<0.05$) among the diets. The apparent digestibility of N was lower for the control diet than for any other treatment ($P<0.05$). S1190 and S1198 supplemented diets had significantly ($P<0.05$) higher N digestibilities

than all the other diets. There was a decline in true digestibility of CP ($P<0.052$) with increasing tannin content of the supplements. Faecal N, urinary N and urinary N per kg N excreted, differed significantly ($P<0.0001$) between the diets. With increasing tannin levels (among *Sesbania* accessions) there was a significant ($P<0.05$) decrease in urinary N per kg N excreted (S1190> S1198> S10865> S15019> S15036) and an increase ($P<0.05$) in faecal N (S1190< S1198< S10865< S15036< S15019). Supplementation increased faecal N output and N retention significantly ($P<0.0001$). Among the forage supplements, N retention was significantly ($P<0.0001$) lower in sheep supplemented with lablab, tagasaste, leucaena, S15019 and goetzei than those supplemented with S1190, S1198, S15036 and S2024. No significant ($P>0.05$) difference was observed for N retention per kg N digested among the forages. The estimated microbial protein varied from 26.2 (control diet) to 37.6 g/ day (S2024) and differed significantly ($P<0.0001$) among diets.

Apparent nitrogen digestibility (ND) was positively correlated ($P<0.001$) with supplement DM and CP degradation after 24 h ($r=0.93$ ($P<0.0001$) and $r=0.85$ ($P<0.001$), the crude protein level ($r=0.87$, $P<0.001$), and negatively correlated to ADF and NDF ($r=-0.87$ and -0.87 ($P<0.001$), respectively). No significant ($P>0.05$) correlation (Table 4) observed between in-vivo dry matter digestibility and N digestibility ($r=0.18$). The tannin levels were negatively related to DM and N

digestibility, DM and CP degradation after 24 h, rate of degradation and NDF.

Discussion

Correcting dietary protein deficiencies can have the following effects in ruminants: increasing the microbial degradation of feed in the rumen and/or improving the animal's metabolic capacity to use energy, both of which lead to an increase in the voluntary intake of digestible organic matter and in animal production. Metabolizable protein requirements of ruminants are met primarily from rumen microbial protein and from dietary protein that escapes the rumen undegraded [Robinson et al., 1991]. This was clearly evident in the estimated microbial protein synthesis and nitrogen retention of the animals supplemented with the browses irrespective of the browse tannin levels and the live weight changes. Supplementation increased significantly ($P<0.0001$) microbial protein synthesis in line with observations made by Oosting [1993]. The high N content of the browses makes them good protein supplements and when fed at the level of 180 g per day supplied moderate levels of rumen-available N that could effectively be trapped for microbial synthesis. However, the presence of polyphenolics such as tannins present in many of the browses could impair their utility, whereas at low levels, condensed tannin increased N retention [Barry and Manley, 1984]. Condensed tannins have been reported in *Leucaena* [Ahn et al., 1989], *Chamaecytisus palmensis* [Borens and Poppi, 1990] and *Sesbania* [Reed, 1986], while *Sesbania* spp are also known to be rich in saponins [Dorsaz et al., 1988].

Tannin levels in lablab, tagasaste, *S. sesban* accessions and *S. goetzei* indicated that levels of anti-nutritional factors such as tannin cannot be used alone to determine the suitability of a browse species as a protein supplement. Factors such as reactivity, structure, molecular weight and interactions of different secondary compounds in the plant are important [Barry et al., 1986; Waghorn et al., 1994]. This was clearly demonstrated by comparing leucaena with lablab, tagasaste, S1190, S1198, S10865, S15019 or S15036. As the level of tannin increased (among *Sesbania* accessions), there was a corresponding increase in the estimated escape protein and a decrease in the rate of degradation and true digestibility of the protein which could be due to tannins forming indigestible complexes with nutrients and inhibiting enzymes [Reed et al., 1985]. Supplements with a high degradation rate such as S1190 and S1198 had low estimated escape protein, high N digestibility and probably a poor synchronization pattern of energy and N. Forage with a high proportion of escape protein are used more efficiently [Buxton, 1996]. Results from this study indicate that forages with intermediate rates of degradation such as S10865, S15019 and S2024 had good qualities as protein supplements to poor quality roughages because of their bypass protein and true digestibility of the protein.

Supplementation of teff straw with *S. sesban* accessions (with increasing levels of tannins) tended to increase live weight gain up to a maximum, beyond which the live weight gain decreased. This tendency is in agreement with the findings of Reed and Soller [1987] and Reed et al. [1990]. Tannins in browse can have both beneficial and negative effects on N metabolism in ruminants. The positive effects of tannins on protein utilization have practical importance because problems associated with extensive proteolysis and/or deamination in the rumen, limit production in modern feeding systems [Beever et al., 1989]. Tannins form complexes with

proteins at higher levels to make the protein unavailable, and the effects on carbohydrate digestion have been ascribed to complexing of condensed tannins with microbial extracellular enzymes [Mueller-Harvey et al., 1987]. However, it is also possible that in ruminants fed high-tannin legumes, there is an overall shortage of rumen-degradable N and that it is this insufficiency which impairs the digestibility of structural carbohydrates [D'Mello, 1992]. This could partly explain the decline in performance of the animals fed *S. sesban* accessions with high levels of tannins. These results suggest that an intermediate level of tannin in *S. sesban* leaves had beneficial effect on protein digestion and metabolism.

Increasing levels of tannins (among Sesbania accessions) was also associated with increasing levels of faecal N and decreasing levels of urinary N. This tendency agreed with the findings of Woodward and Reed [1989] and Wiegand [1995]. Excessive amounts of forage protein nitrogen may be excreted as urea in animal urine, which can limit animal production and a large percentage of that N is lost to the environment as ammonia. The implication of the shift of N excretion from urine to faeces is important especially to poor resource farmers, natural resource management and sustainability. The advantages of tannin-complexing dietary nutrients, especially protein, are obvious for the smallholder, who to a large extent depends on tanninferous forages for protein supply to his stock, and on faeces to improve the soil fertility of his crops.

High levels of condensed tannins (TC) were associated with high levels of lignin ($r=0.86$ $P<0.001$) in this study. This agreed with the observation made by Harkin [1973] and Wong [1973] that tannin and lignin are both polyphenolic compounds, and their monomers are synthesized in plants by the same shikimic biochemical pathway. Positive correlations between ADF, lignin and insoluble proanthocyanidins have also been found in *Acacia* spp [Reed, 1986], 23 *Sesbania* accessions [Nsahlai et al., 1993] and sorghum grain [Reed, 1987]. Conversely, negative correlations were observed between tannins and parameters of degradation (D24, N24, kd) as well as NDF and agreed with the observations made by Nsahlai et al., [1995]. Tannin-protein and tannin-carbohydrate complexes have low solubility in aqueous organic solvents and in the 72% sulphuric acid used in the analysis of lignin [Wiegand, 1995]. The poor relationship observed between N and DM digestibility *in vivo* could be attributed to the presence of tannins and its depressing effect on DM and CP degradability [Woodward and Reed, 1989; Ahn et al., 1989]. However, N digestibility in vivo can be predicted from the D24 ($r=0.93$), N24 ($r=0.85$), CP ($r=0.87$), NDF ($r=-0.87$) and ADF ($r=-0.87$).

In this study, the effect of supplementing teff straw with *S. sesban* 2024 was not commensurate with the level of condensed tannins (Figure 1). This could partly be attributed to its high CP content which resulted in a significantly higher ($P<0.0001$) N intake than the other supplements. *S. Sesban* 2024 unlike the other *Sesbania spp* is well adapted to waterlogged situations.

Conclusion

The browse supplements had varied effects on the utilization of dietary protein and this was probably influenced by different types and concentration of phenolics. Supplementation increased nitrogen retention about 9-fold (0.3 vs 2.7).The results from this study indicate that

tanninferous forages can be suitable protein sources as long as the negative effects of tannins on increasing output of faecal N is less than their positive effect on reducing urinary-N loss. The positive responses obtained were attributed to the abilities of the browse supplements to overcome a nitrogen deficiency in teff straw by providing more ruminally degradable N and/or estimated escape N.

Acknowledgements

The authors wish to express their appreciation to the staff of ILRI Debre Zeit station.

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Chapter 8

Effect of *Leucaena* and *Sesbania* supplementation on body growth and scrotal circumference of Ethiopian highland sheep and goats *fed teff straw basal diet*

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Submitted: Livestock Production Science

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Abstract

The long term effect of supplementation of *Leucaena pallida* and *Sesbania sesban* on growth and reproduction performance was determined on 30 male Ethiopian highland sheep and 25 East African goats. Unchopped teff straw (*Eragrostis tef*) was given *ad libitum* and supplemented with either wheat bran (150 g), *Leucaena* (200 or 400 g) *or Sesbania* (200 or 400 g). The animals were blocked (by species) on live weight and scrotal circumference (SC), and randomly assigned within blocks to the five dietary treatments in a randomized complete block design. Animals supplemented with 400 g of the browses had significantly higher ($P<0.05$) intake of DM and live weight gain than the other treatments. Sheep had significantly higher ($P<0.05$) teff straw intake than goats (47.3 and 38.7 g $kgW^{-0.75}$, respectively). The correlation between SC and body weight was high and significant in goats ($R^2=0.70$, $P<0.001$) and lower in sheep ($R^2=0.43$, $P<0.01$). Live weight gain and scrotal circumference changes were significantly ($P<0.01$) different between treatments in both animal species. Supplementation with browses increased faecal nitrogen output and nitrogen retention. The results from this study indicated type and level of supplement variations on the growth and reproductive performance of sheep and goats.

Key words: Leucaena, Sesbania, growth, scrotal circumference, sheep, goats

Introduction

Tree fodder has been used as livestock feed for many years and can provide sufficient nutrients to meet the nutritive demand of livestock. In rural areas, ruminants often browse the palatable foliage of a wide variety of trees and shrubs. A vast array of trees serves as animal fodder in the tropics and subtropics, often browsed or casually lopped and fed (Skerman, 1977; Le Houèrou, 1980). *Sesbania* and *Leucaena* species have widely been adopted. Both species produce ample quantities of fodder with excellent quality. However, before their full integration into traditional farming systems, questions relating to adaptability under a wide range of environmental conditions, responses to a wide range of cultural treatments and animal responses have to be addressed.

In the 1970's and early 1980's, use of *Leucaena leucocephala* and *Sesbania sesban*

as fodders became widespread and popular. Many feeding trials, reforestation, agroforestry and soil conservation projects made use of or made reference to *L. leucocephala* and it was looked upon as a panacea species. Unfortunately, this bias has now proved inadvisable because in recent years, the *Leucaena* psyllid has proved to be a significant factor determining the continued use and expansion of this valuable browse species. Although when offered in fresh and dry forms, *Leucaena pallida* was ranked lower than *L. leucocephala* by both sheep and goats (Kaitho et al., 1997), it is likely to be a good replacement of *L. leucocephala.* Siaw et al. (1993) observed no differences in ruminal degradation characteristics and gas production and in a recent palatability study with sheep, *L. pallida* was ranked third among other 39 browses when fed dry and was placed in the same cluster group as *L. leucocephala* (Kaitho et al., 1996). *Leucaena pallida* has high edible dry matter yield and excellent coppicing ability (Wheeler and Brewbaker, 1989). It has also been observed to be more cold tolerant and psyllid resistant (Bray, 1984) than *L. leucocephala.*

Data on the effect of feeding *L. pallida* and *S. sesban* on small ruminants reproduction is scarce (especially in goats). Some studies of *L. leucocephala* on cattle indicate no deleterious effect on oestrous cycle, conception rate, gestation length, calf birth weight and calf pre-weaning mortality (Hamilton et al., 1971). Jones et al. (1989) observed an improvement in calving percentage from 54% to 75% in cows grazing *L. leucocephala* for 4 years. Holmes et al. (1981) suggested that cows eating high levels of *L. leucocephala* conceived but aborted within the first 3 months. Abortion was ascribed to either anti-mitotic effect of mimosine or to the goitrogenic effect of 3-hydroxy-4(1H)-pyridone (DHP), a ruminal metabolite of mimosine.

Most feeding trials on *Leucaena* and *Sesbania* supplementation have been for short durations and focused mainly on feed intake, feed conversion and average daily gain. Information regarding their effects on the reproductive physiology of small ruminants is scarce and the available data are contradictory or inconclusive at best. This study was therefore designed to determine the long term effect of supplementation of *Leucaena pallida* (ILCA 14191) and *Sesbania sesban* (ILCA 1190) on the growth and reproductive performance of male Ethiopian Highland sheep and goats fed on teff straw (*Eragrostis tef*) basal diet. In this paper we compared the effects of these browses as supplements on dry matter intake, live weight gain, digestion and scrotal circumference changes in sheep and goats. Their effects on histological testicular parameters and sperm characteristics are discussed elsewhere (Tegegne, Kaitho, Umunna and Nsahlai, in preparation).

Materials and methods

This study was carried out at the International Livestock Research Institute (ILRI) research farm at Debre Zeit, Ethiopia. Unchopped teff straw was given *ad libitum* (i.e. about 1.5 times the previous day's intake) supplemented with 150 g wheat bran (control), 200 g *L. pallida* (L1), 400 g *L. pallida* (L2), 200 g *S. sesban* (S1) or 400 g *S. sesban* (S2). The browse leaves were previously air dried and stored in bags. All the forages were grown on the farm (1850 m above sea level; annual rainfall 800 mm).

Thirty post-pubertal male Ethiopian highland sheep (23.7 kg ; SD=1.23; average age of 18 months) and twenty-five male East African goats (18.6 kg ; SD=2.06; average age of 14 months) bought from nearby markets were blocked (by species) on live weight and scrotal circumference, and randomly assigned within blocks to the five dietary treatments in a complete randomized block design. The testis were palpated before purchase. The breed of the sheep is a hair type from the Ethiopian highlands and rams have a mature weight of 35-45 kg, while the mature weight of goats is 30-40 kg. The animals underwent standard quarantine procedures for 21 days before the start of the experiment. All the animals were housed in individual pens on slatted floor and had access to water and mineral lick *ad libitum*. The supplement was fed in plastic buckets. The quantity of teff straw and supplements offered and refused were recorded daily during the six month period. The refusals were removed, weighed and sampled before the morning feeding (08.00 h). The animals were weighed fortnightly. Scrotal circumference was measured at the point of greatest paired testicular diameter, using a metal scrotal measuring tape, with the testes hanging loosely in the scrotum. The same person measured the testicular size of each animal fortnightly.

The feeding trial was immediately followed by a 10-day digestibility trial. Four animals from each treatment were put in metabolic crates (in two groups) and allowed 3 days to adapt to the crates and the manure collection bags. During this period, forages on offer and refusals were sampled daily for the determination of dry matter (DM) and nitrogen (N). Urine was collected over 25 ml of 10% hydrochloric acid. After weighing, 10% of urine and faeces collected daily was frozen and at the end of collection period pooled on animal and sub-sampled for chemical analysis.

Chemical analysis

Samples of feeds and refusals were ground to pass a 1- mm screen using a Wiley mill, while frozen faecal samples were ground using a mortar and pestle. Dry matter was assayed on the offered and refused feed and faeces using the method described by the AOAC (1990). All other analyses were determined using air-dried feed samples and frozen faecal samples. Analyses for ash and Kjeldahl nitrogen (N) in forages and faeces

were according to AOAC (1990) standard procedures. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were analysed using the method of Van Soest and Robertson (1985). Colorimetric determination of condensed tannins (TC) was done according to the method of Porter et al. (1986). Mimosine in *Leucaena* was determined by the method of Tangendjaja and Wills (1980). After repeatedly extracting the material with 0.1M of HCl acid, the supernatant was filtered and purified by cation exchange resin and washed by ethanol to remove phenolic compounds. Mimosine was finally eluted by 1 M di-ammonium hydrogen phosphate ($(NH_4)_2HPO_4$) with pH adjusted to 8.5.This solution was injected into the HPLC equipped with a μBondapak C18 column and Ultra-Violet detector. Phytoestrogens (daidzein, quercetin and genistein) were determined by hydrolysis of 0.5 g of sample in 6 ml of 1 M HCl and 45 μg of flavon as the internal standard for 2 hours at 100°c. 12 ml of acetonitril was added, and after shaking and centrifugation an aliquot of 25 μl was transferred into an HPLC column (Novapack RP-C18 column). As eluent a gradient of acetic acid with acetonitril was used. Detection was done with diode array detector (DAD) at 260 nm. Presence of saponin was estimated by preparing extracts of the leaf samples in water. Persistent foam on the liquid surface after shaking indicated the presence of saponins.

Data and statistical analysis

Live weight change (LWG) and change in scrotal circumference for each animal over the experimental period were calculated by regression analysis. Live weight changes, changes in scrotal circumference, intake and in-vivo digestibility coefficients were subjected to analysis of variance using the General Linear Model (GLM) procedure available in SAS (1987). Live weight was used as covariate to scrotal circumference in identifying differences between treatment groups. Metabolisable energy (ME) was calculated from feed ingredients *in vitro* digestibility results (Alderman, 1985).

Results

Crude protein (Nx6.25) contents for *S. sesban, L. pallida*, wheat bran and teff straw were 261, 296, 166, 36 g kg^{-1} DM, respectively (Table 1). Teff straw and wheat bran had higher fibre content than the browses. However, the browses had higher NDF bound N. *Leucaena pallida* had higher quercetin and total soluble proanthocyanidins than *S. sesban*. All the feed ingredients had low levels of genistein and daidzein. Mimosine and saponins were detected in *L. pallida* and *S. sesban*, respectively.

There was no significant effect ($P>0.05$) of the different types of supplement on teff straw intake in both sheep and goats (Table 2). However, total intake of dry matter (DM) and digestible organic matter (DOM), were significantly affected ($P<0.001$) by the level

Table 1. Chemical composition of the feed ingredients.

	Teff straw	Wheat bran	*S. sesban*	*L. pallida*
DM (g kg^{-1})	873	891	899	812
Ash (g kg^{-1} DM)	84	39	81	59
CP (g kg^{-1} DM)	36	166	261	296
NDF (g kg^{-1} DM)	790	469	204	404
NDFN (g kg^{-1} NDF)	2.1	6.4	10.2	19.3
ADF (g kg^{-1} DM)	463	155	161	196
TC (g kg^{-1} DM)	nd	nd	2.4	35.9
Mimosine (g kg^{-1} DM)	nd	nd	nd	3.5
Daidzein (µg g^{-1} DM)	<2	<2	<2	<2
Genistein (µg g^{-1} DM)	<2	<2	<2	<2
Quercetin (µg g^{-1} DM)	<20	<20	640	2350
Saponin	ndd	ndd	+++	ndd

DM: dry matter; CP: crude protein; NDF: neutral detergent fibre; NDFN: neutral detergent fibre bound nitrogen; ADF: acid detergent fibre ; TC: total soluble proanthocyanidins; nd: not determined; ndd: not detected.

Table 2. Average daily feed intake of sheep and goats fed teff straw and supplemented with wheat bran or two levels of *Leucaena pallida* and *Sesbania sesban*.

	DMI (g $kgW^{-0.75}$)				
Treatment	Teff	Supp	Total	DOMI (g $kgW^{-0.75}$)	ME (MJ)
Sheep					
Teff + wheat bran	47.9	11.8	59.6	28.4	5.07
Teff + *L. pallida*	48.6	16.0	64.6	30.2	5.14
Teff + *L. pallida*	45.2	30.4	75.7	40.0	6.45
Teff + *S. sesban*	48.4	15.5	63.9	31.3	5.32
Teff + *S. sesban*	46.4	24.7	71.1	37.6	6.36
SED (n=6)	1.24		1.81	0.92	
F-test					
Treatment	NS		***	***	
Level	**		***	***	
Goats					
Teff + wheat bran	39.7	14.7	54.4	26.5	3.85
Teff + *L. pallida*	40.1	19.9	59.9	28.8	3.91
Teff + *L. pallida*	35.6	36.5	72.1	37.3	5.25
Teff + *S. sesban*	40.4	19.1	59.4	31.2	4.03
Teff + *S. sesban*	37.5	31.4	68.9	36.8	5.02
SED (n=5)	2.22		2.67	1.36	
F-test					
Treatment	NS		***	***	
Level	*		***	***	

Supp: supplement; DMI: dry matter intake; DOMI: digestible organic matter intake; ME: metabolizable energy; W: body weight (kg); * : P<0.05; * * : P<0.01; *** P<0.001; NS: not significant.

and the type of supplement. Animals supplemented with 400 g of the browses had significantly higher (P<0.05) intake of DM and DOM than those offered 200 g. Sheep had significantly higher (P<0.05) teff straw intake than goats (47.3 and 38.6 g $kgW^{-0.75}$, respectively). The browse supplement contributed 24-40% of DM intake in sheep and 32-50% in goats. Substitution rate (g basal diet replaced by 1 kg of browses supplement) of teff straw between the high and low level of supplementation remained below 100 g and except for the goats supplemented with *S. sesban*.

Initial live weight and scrotal circumference did not differ significantly (P<0.05) between dietary treatments within animal species (Table 3, Figure 1 and Figure 2). Live weight gain and scrotal circumference changes (ΔSC) were significantly (P<0.01) different between treatments in both animal species. LWG and ΔSC were significantly

Table 3. Average daily live weight gain and scrotal circumference changes of sheep and goats fed teff straw and supplemented with wheat bran or two levels of *Leucaena pallida* and *Sesbania sesban*.

		LWG($g\ d^{-1}$)						
Treatment	initial W (kg)	P1	P2	P3	Overall	initial SC (cm)	SC (mm/d)	SCW
Sheep								
Teff + wheat bran	23.8	34.3	23.7	12.0	19.9	24.1	0.18	0.0011
Teff + *L. pallida*	23.8	19.2	26.9	18.7	20.9	24.3	0.19	0.0001
Teff + *L. pallida*	23.8	44.3	39.3	21.4	39.1	24.5	0.25	-0.0043
Teff + *S. sesban*	23.5	24.2	10.5	19.5	16.5	25.3	0.08	-0.0025
Teff + *S. sesban*	23.7	34.8	16.0	28.1	26.2	25.4	0.08	-0.0066
SED (n=6)	0.76				3.7	7.7	0.05	0.0016
F-test								
Treatment	NS				***	NS	**	**
Level					***		NS	**
Goats								
Teff + wheat bran	18.7	15.4	11.3	-9.5	4.9	18.8	0.18	0.0070
Teff + *L. pallida*	18.4	15.3	13.3	1.8	11.7	18.6	0.15	0.0016
Teff + *L. pallida*	18.7	36.0	45.6	20.5	32.3	18.6	0.42	0.0046
Teff + *S. sesban*	18.5	14.3	-9.1	4.8	-0.3	19.3	0.00	0.0039
Teff + *S. sesban*	18.8	22.6	-17.9	-2.2	-1.0	19.5	0.05	0.0029
SED (n=5)	1.42				4.2	13.6	0.09	0.0034
F-test								
Treatment	NS				***	NS	***	NS
Level					**		*	NS

W: body weight (kg); LWG: live weight gain; P1: 1-60 days; P2: 60-120 days; P3: 120-180 days; overall: 180 days; SC: scrotal circumference; ΔSC: scrotal circumference change; SCW: rate of change of SC:W ratio ; * : P<0.05; * * : P<0.01; *** P<0.001; NS: not significant.

($P<0.01$) higher in L2 than all the other treatments. Sheep had significantly higher ($P<0.01$) LWG than goats. LWG significantly ($P<0.05$) decreased with time in both animal species. Growth was higher for all animals within the initial 2 months compared with the last 2 months. Increasing the amount of *L. pallida* supplemented significantly increased LWG and ΔSC in both sheep and goats. Animals supplemented with *S. sesban* had significantly lower ($P<0.05$) ΔSC than the other treatments. The correlation between SC and body weight was high and significant in goats ($r^2=0.69$, $P<0.001$) and lower in sheep ($r^2=0.16$, $P<0.01$).

Voluntary intake, digestibility, N excretion and N retention values during the metabolism trial are given in Table 4. The browse supplemented animals had significantly ($P<0.05$) higher total DM, organic matter (OM) and N intake, than the ones supplemented with wheat bran. *Sesbania sesban* supplemented diets had significantly higher ($P<0.05$) digestibilities of DM, OM and N than the other diets in goats, while the same was true for 400 g browse supplement treatments in sheep. Faecal N and urinary N differed significantly ($P<0.05$) between the diets. Supplementation with browses increased significantly ($P<0.05$) faecal N output and N retention in both sheep and goats. Nitrogen retention was significantly ($P<0.05$) higher in animals supplemented with 400 g browse than 200 g.

Table 4. Effect of supplementing teff straw with wheat bran and browses on dry matter intake, digestibility, N excretion and N retention in sheep and goats (metabolism study).

	Intake (g $kgW^{-0.75}d^{-1}$)			Digestibility (g kg^{-1})			Excretion (g d^{-1})		
Treatment	DM	OM	N	DM	OM	N	FN	UN	NR
Sheep									
Teff + wheat bran	53.4	49.5	0.55	476	514	427	3.6	3.1	-0.39
Teff + *L. pallida*	64.9	59.8	1.03	471	506	482	6.2	4.1	1.60
Teff + *L. pallida*	69.6	64.5	1.61	531	570	557	8.9	4.3	7.01
Teff + *S. sesban*	63.3	58.0	0.94	492	534	502	5.3	1.6	3.75
Teff + *S. sesban*	72.6	66.6	1.5	545	577	645	6.4	1.6	10.05
SED (n=4)	3	2.77	0.04	13.1	13.0	31.6	0.55	0.58	0.60
Goats									
Teff + wheat bran	46.1	42.9	0.56	496	525	468	2.8	1.1	1.39
Teff + *L. pallida*	52.8	48.8	1.08	496	521	527	5.0	2.3	3.31
Teff + *L. pallida*	56.9	53	1.79	521	557	558	8.2	6.0	4.33
Teff + *S. sesban*	51.9	47.6	1.07	540	571	627	3.4	2.8	2.83
Teff + *S. sesban*	66.9	61.4	1.79	552	582	693	5.1	4.5	6.96
SED (n=4)	3.11	2.86	0.06	13.1	10.8	3.0	0.53	0.21	0.55

DM: dry matter; OM: organic matter; N: nitrogen; FN: faecal nitrogen; UN: urinary nitrogen; NR: nitrogen retention.

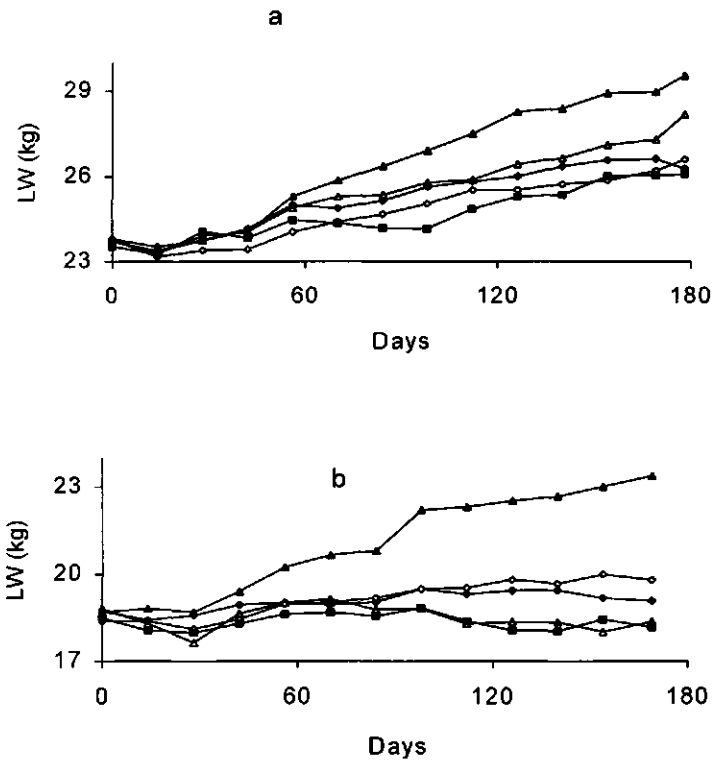

Figure 1. Live weight changes of sheep (a) and goats (b), fed teff straw basal diet supplemented with wheat bran (◆), 200 g *L. pallida* (◇), 400 g *L. pallida* (▲), 200 g S. sesban (■) or 400 g *S. sesban* (△).

Discussion

Ruminants fed a better quality diet tend to compensate through protein repletion and consequently high initial growth rates. On meeting body protein requirements and as the animals matures, they deposit more fat than protein; thus, efficiency of gain reduces tremendously in the latter phase. This might have partly contributed to the decline in live weight gain with time (Table 3), however, there are strong indications that accumulation

of anti-nutritional factors had a significant role. Among species of ruminants, there are differences in susceptibility to plant toxins. Sheep are considered more resistant to alkaloids than are cattle (Cheeke, 1988) and in numerous other instances, goats are more resistant than sheep to poisonous plants (Cheeke and Shull, 1985; Kellerman et al., 1988). To a considerable extent, these differences among ruminants are a reflection of feeding strategy and the nature of diet upon which the species evolved. Cattle evolved as grazing animals on grasslands, goats are browsing animals, consuming non-grass herbaceous plants as a major component of their natural diet, whereas sheep are intermediate feeders (Van Soest, 1994).

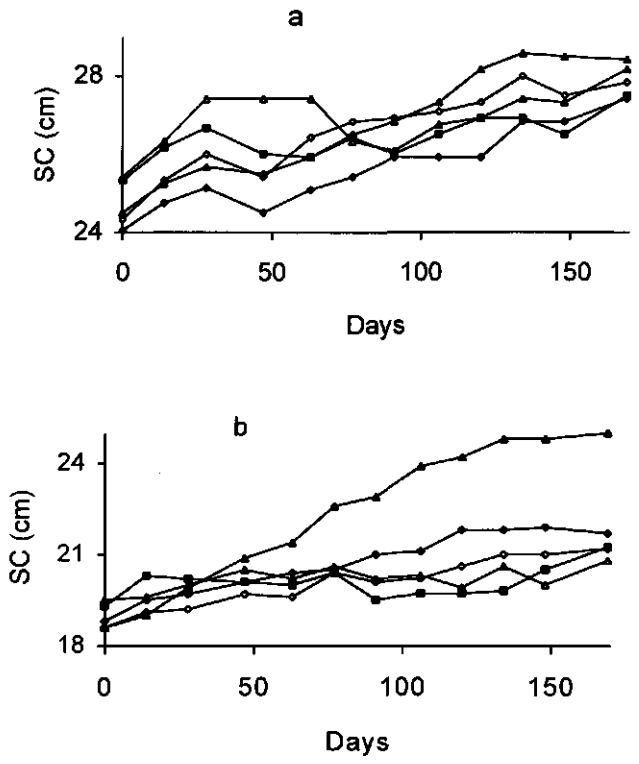

Figure 2. Scrotal circumference of sheep (a) and goats (b) fed teff straw basal diet supplemented with wheat bran (◆), 200 g *L. pallida* (◇), 400 g *L. pallida* (▲), 200 g *S. sesban* (■) or 400 g *S. sesban* (△).

Nutritional deficiency may be caused by general underfeeding with roughage of poor quality. Animals fed under these conditions tend to be retarded in body development and the sexual organs may share in this retardation. The above effects in reproduction are usually directed at the level of the anterior pituitary gland, which fails to secrete enough gonadotropins to stimulate the testis to produce testosterone and semen (Asdell, 1955). The provision of protein, energy and mineral supplements is a prerequisite for a successful management for good reproductive performance of animals (Topps, 1977). Low protein (1-3% crude protein) and low energy (34-40% total digestible nutrients) content of poor quality hay in the dry season have resulted in loss of body weight and corresponding low levels of reproduction in cattle (Topps, 1977). Rams receiving high energy diets were better in terms of body condition, semen production, scrotal circumference and gonadotropin output than those on low energy diets (Alkass and Bryant, 1982).

This study confirms earlier reports that have indicated a significant association between plane of nutrition, body weight and scrotal circumference (Alkass and Bryant, 1982; Rekwot et al., 1988; Mukasa-Mugerwa and Ezaz, 1992). Sperm production and testicular size are influenced by the plane of nutrition (Cameron et al., 1984). Experiments using Merino rams have shown that testicular size and live weight of grazing animals increase during the winter/spring period when the pasture production is at a maximum (Masters and Fels, 1984). The results of this study are supported by Oldham et al. (1978) and Murray et al. (1991) who found that protein supplementation of animals increased scrotal circumference and therefore, testicular size in rams. Sperm production in rams is related to testicular size (Cameron et al., 1984) and the fertility can be predicted from changes in the size of testicles. Scrotal circumference measurements correlate well with testicular weight (Lino, 1972). Testes size is itself related to sperm production particularly in growing ram lambs (Yarney et al., 1990). There is an established relationship between ram live weight and testicular size (Knight 1977; Braun et al. 1980; Mukasa-Mugerwa and Ezaz, 1992), with big rams generally having bigger testes. It has also been shown that rams with larger testes were more effective in mating ewes successfully (Barwick et al., 1989) than counterparts with smaller testes. Scrotal circumference measurements correlated well with live weight in goats in this study (Figure 1 and 2). The lack of good relationship in sheep is probably because the animals were more mature at the beginning of the experiment.

Some studies have shown that the proportional increase in testicular size may be greater than the accompanying increase in body weight (Oldham et al., 1978; Martin et al., 1987; Schoeman and Combrink, 1987). The decline in the ratio of scrotal circumference to live weight supports the finding that testicular tissue is particularly sensitive to nutritional fluctuations, responding to losing or gaining weight more quickly than the rest of the body. The sensitivity of testicular tissue to undernutrition has been

highlighted by Oldham et al. (1978) and Masters and Fels (1984), but appears to be equally sensitive to improved nutritional status, as indicated by the nitrogen balance in this study.

Animals supplemented with higher level of *L. pallida* exhibited the highest growth rate although, shedding of fleece was noticed after 80 days in both sheep and goats. *Leucaena* contains mimosine and the accumulation of ruminal by-product DHP leads to goitre, loss of appetite, excess salivation, hair loss and loss of weight (Jones, 1979). However, this effect seems to occur if *Leucaena* constitutes a high proportion of the animal's diet (>50%) and when the animals are maintained on the same diet for an extended period. *Leucaena* and *Sesbania* species have been recommended for feeding to livestock because of their high protein (25-30%) and palatable forage. In this study, *Leucaena* supplementation had positive effect on reproduction as indexed by scrotal circumference changes. Similarly, when *Leucaena* was fed as a sole diet, toxic symptoms were reported due to its high mimosine (Hamilton et al., 1971), however reproductive efficiency was unaffected.

The sheep and goats in this study exhibited different preferences for the browses as indicated by the contribution of the browse to the diet (24 to 40% and 33 to 50%, respectively). The surprising observation was that even when the goats were losing weight, the ratio of teff straw to *Sesbania* supplement was maintained at the same level. The relatively higher *Sesbania* intake in goats than in sheep could account for the differences observed in performance. Prolonged uninterrupted intake of *S. sesban* as had a negative effect on LWG and ΔSC especially in goats. This could be attributed to un- identified phytochemical(s) such as saponins. Numerous plant chemicals have effects, mainly inhibitory, on animal reproduction. Hughes (1988) postulated that modulations of the fertility of herbivores may be another means by which plants protect themselves. When subjected to high intensity predation, some plants may be able to respond by inhibiting the reproduction of herbivores or modulating population cycles of small herbivores such as rabbits (Bryant et al., 1992), thus having a long-term effect of decreasing predation. Phytochemicals have regulatory role in reproduction of small herbivores such as meadow voles and lemmings (microtine rodents) (Berger et al., 1981; Sanders et al., 1981) and have been attributed to the adverse effects on reproduction of sheep grazing subterranean clover (Adams, 1989).The results from this study have indicated type and level of supplement variations in reproductive performance as indexed by scrotal circumference changes in sheep and goats.

Acknowledgements

The authors thank Olga Karnafil, Kassahun Zewdie and sheep barn staff at ILRI Debre Zeit station for their invaluable assistance.

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Chapter 9

Effect of feeding graded levels of *Leucaena leucocephala*, *Leucaena pallida, Sesbania sesban* and *Chamaecytisus palmensis* as supplements to Ethiopian highland sheep fed teff straw

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Abstract

The effect of feeding graded levels of *Leucaena leucocephala*, *Leucaena pallida*, *Sesbania sesban* and *Chamaecytisus palmensis* supplements on intake, digestibility and live weight changes was evaluated using one hundred and two male Ethiopian highland sheep in a 90-day trial. Teff straw (*Eragrostis tef*) was fed *ad libitum* (control diet), or supplemented with graded levels (15, 30, 45, 60% of ration dry matter intake) of *L. leucocephala, L. pallida, C. palmensis* or *S. sesban* in a randomized complete block design. Significant ($P<0.05$) decrease in teff straw intake was observed, as the level of supplement increased. Substitution rates (g kg^{-1} supplement) increased with increasing levels of supplementation. Substitution rate varied from *162 to 528* in *L. pallida*, *-89 to 312* in *L. leucocephala*, -566 to 231 in *S. sesban* and -10 to 134 in *C. palmensis* supplemented diets. Dry matter and digestible organic matter intake increased significantly ($P<0.05$) with increasing *level of L. leucocephala, C. palmensis* and *S. sesban*, but not in *L. pallida*. Live weight gain increased significantly ($P<0.01$) with increasing level of browse supplementation. The animals fed the control diet lost weight (-24.4 g d^{-1}) while the supplemented ones gained weight in the range of 6.5 - 65.2 g d^{-1}. The maximum live weight gain (65.2 g d^{-1}) was observed in sheep fed a diet with 60% *L. pallida*. The optimum levels of browse supplementation in terms of live weight gain per g supplement were 45, 45, 30, 30% DM of total ration for *L. leucocephala, L. pallida, C. palmensis* and *S. sesban*, respectively. A close relationship between live weight gain and amount of supplement was observed. The digestibilities of DM, OM, N and supplement DM increased significantly ($P<0.05$) with increasing level of supplementation. No significant ($P>0.05$) differences were observed in NDF digestibility. Faecal nitrogen, urinary nitrogen output and nitrogen retention increased significantly ($P<0.0001$) with level of supplementation.

Key words: browse, intake, live weight gain, digestibility, degradability, sheep

Introduction

Poor nutrition caused by inadequate amounts and poor quality of feed is one of the major causes of low livestock productivity in tropical areas. Conventional feeds such as

grains and oilseed cakes are not produced in sufficient amounts to meet the requirements of man and livestock in these areas. Grass and legume forages are also not produced in sufficient amounts, because subsistence farmers, who constitute the majority of farmers, cannot provide these crops with the required agronomic inputs. Multipurpose trees and shrubs (browses), which establish easily and don't require extensive agronomic inputs, and constitute potentially valuable sources of supplementary feeds that subsistence and medium scale livestock farmers in the tropics could use to improve livestock nutrition and productivity. Browse (legumes) represent a source of nitrogen which may be utilized to increase the intake and digestibility of low quality forages such as crop residues and mature tropical grasses and to improve the performance of livestock fed on them (Bates et al., 1988; McMeniman et al., 1988).

There is extensive and diverse literature on the effects of browse supplementation on the productivity of cattle, sheep and goats (Norton, 1994). Browse leaves, particularly *Leucaena leucocephala, Leucaena pallida*, *Sesbania sesban* and *Chamaecytisus palmensis*, have been used as supplements to a wide range of forages and agricultural by-products (Tanner et al., 1990; Khalili and Varvikko, 1992; Varvikko and Khalili, 1993; Goodchild and McMeniman, 1994; Bonsi, 1995). They have been incorporated into concentrate rations as substitute for more expensive protein sources, and used as supplements to low quality grasses and agricultural by-products (Wahyuni et al., 1982; Carew, 1983; Khalili and Varvikko, 1992; Varvikko and Khalili, 1993). These authors observed an increase in total dry matter intake and an overall improvement in diet digestibility with supplementation. In addition to animal response, nylon bag degradation, gas production and digestibility in small intestine (mobile nylon bag) of these browse species have been studied (Siaw et al., 1993; Kaitho et al., 1997). However, there are few experiments investigating the effects of increasing levels of browse supplementation to ruminants. This information is needed if farmers are to be advised on the optimum level of supplementation. Therefore, the objective of this study was to find out the effects of feeding graded levels of *Leucaena leucocephala*, *Leucaena pallida*, *Sesbania sesban* and *Chamaecytisus palmensis* supplements on the intake, live weight changes and digestibility and to establish optimum supplementation levels of these browses to teff straw (*Eragrostis tef*) for Ethiopian highland sheep.

Materials and methods

Two experiments were conducted at the International Livestock Research Institute (ILRI) research farm at Debre Zeit, Ethiopia. Air-dried leaves of *Leucaena leucocephala, Leucaena pallida, Chamaecytisus palmensis* and *Sesbania sesban* were used to supplement sheep fed teff straw. Branches of these browse species were lopped, leaves allowed to dry (2 days) and removed from the branches by beating with sticks.

All the forages were grown on the farm (1850 m a.s.l.; annual rainfall 800 mm).

Experiment 1

One hundred and two Ethiopian highland sheep (average body weight of 19.5 kg; SD=1.66; average age of 14 months) bought from nearby markets were blocked on live weight and age into six blocks and randomly assigned within block to the 17 dietary treatments in a randomized complete block design. The dietary treatments consisted of *ad libitum* (refusals >20% offer) teff straw either alone or supplemented with graded levels (15, 30, 45 and 60 % of ration dry matter intake) of *L. leucocephala*, *L. pallida*, *C. palmensis* or *S. sesban*. The legume supplements were fed in plastic buckets and the amount offered was adjusted every two days (per animal) based on actual dry matter intake in order to maintain the set proportions. The quantity of teff straw and supplements offered and refused were recorded daily during the 90-day period. The refusals were removed, weighed and sampled before the morning feeding (08.00 h). All the sheep had access to water and mineral lick *ad libitum*. The sheep were weighed fortnightly.

The feeding trial was followed by a 10-day digestibility trial. Four animals from each treatment were put in metabolic crates (in two groups) and allowed 3 days to adapt to the crates and the manure collection bags. During this period, forages on offer and refusals were sampled daily for the determination of dry matter (DM) and nitrogen (N). Urine was collected over 25 ml of 10% hydrochloric acid. After weighing, 10% of urine and faeces collected daily was frozen and at the end of collection period pooled on animal and sub-sampled for chemical analysis.

Experiment 2

Twelve male rumen-fistulated Ethiopian highland sheep (average body weight of 24.4 kg; SD=1.02; average age of 20 months), were blocked on live weight and randomly assigned within blocks to the four browses in a randomized complete block design. Each animal was fed native hay (CP=6%, NDF=72.4%) *ad libitum* and supplemented with 150 g wheat bran (CP=16.6%, NDF=46.9%) daily. After 15 days of adaptation, rumen degradability of each forage was determined using the nylon bag technique (Mehrez and Ørskov, 1977). After browse incubations, teff straw degradability was determined in three sheep randomly selected from the same group of fistulated sheep using the same procedure. Air-dried samples were milled (2.5 mm screen), and about 2.5 g weighed per nylon bag (14 cm x 8 cm, 41μm pore size, Polymon, Switzerland) were incubated for 0, 3, 6, 12, 24, 48, 72, 96 and 120 hours. After incubation, the bags were washed using a non-automatic washing machine (Tefal alternatic, Finland) without

spinning. The water was changed five times, with each cycle lasting 5 minutes. The bags were dried in a forced-air oven at (60°C) for 48 h, cooled in a desiccator, and weighed.

Chemical analysis

Samples of feeds and refusals were ground to pass a 1- mm screen using a Wiley mill, while frozen faecal samples and rumen incubated residues were ground using a mortar and pestle. Dry matter and ash was assayed on the offered and refused feed and faeces using the method described by the AOAC (1990). All other analyses were determined using air-dried feed samples, frozen faecal samples and oven-dried (60°C) rumen incubated residues. Analyses for Kjeldahl nitrogen (N) in forages, faeces, urine and rumen incubated residues were according to AOAC (1990) standard procedures. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were analysed using the method of Van Soest and Robertson (1985). Condensed tannins (TC) were determined using the HCl-Fe^{3+} method of Porter et al., (1986).

Data and statistical analysis

Live weight gain (LWG) over the experimental period was calculated by regressing body weight (kg) of individual animals measured at 2-week intervals on time (in days). The disappearance of DM from nylon bag was described by an exponential model (Ørskov and McDonald, 1979):

$$P = a + b(1 - e^{-ct})$$

where P is the DM disappearance at time t, 'a' the zero time intercept, 'b' the slowly degradable fraction and 'c' the rate of degradation. The potential degradability (PD) was calculated as (a+b). A passage rate (k_p) of 4% h^{-1} (Umunna et al., 1995) was assumed in order to calculate effective degradability (ED):

$$ED = a + \frac{bc}{k_p + c}$$

The amino acid available for absorption in the small intestine (g $kg^{-0.75}$) were estimated from the digestible OM intake assuming a partial rumen digestion of 0.7 and a microbial protein synthesis of 150 g kg^{-1} rumen digestible OM, of which 0.64 was considered to be true protein (Van Bruchem et al., 1985). The microbial protein synthesis was based on an estimate of 200 g kg^{-1} rumen digestible OM (Oosting et al., 1995) reduced to 150

g kg^{-1} to account for the tannin effect. The dietary amino acid N escaping rumen degradation was calculated assuming an effective rumen degradation of 0.55 and a true digestibility of 0.82 (Kaitho et al., 1997). Supplement digestibility was estimated by the difference method.

DM degradability parameters, LWG, intake and in-vivo digestibility coefficients were subjected to analysis of variance (ANOVA) using the General Linear Model procedure (GLM) available in SAS (1987). To test whether there was any advantage supplementing the animals, the control diet was contrasted against the browse supplemented treatments. The treatment with teff alone was removed from the data when the browse species were compared. The level of supplementation was included in the model because the interactions were significant. Substitution rate was calculated as the amount of basal diet (teff straw) in grammes replaced by one kilogram of browse DM. Regression analysis was carried out to find the relationship between live weight gain and the quantity of supplement offered.

Results

Crude protein (Nx6.25) contents in *L. leucocephala, L. pallida, C. palmensis S. sesban* and teff straw were 153, 195, 209, 304, 29 g kg^{-1} DM, respectively (Table 1). Teff straw had higher fibre content than the browses, however, the browses had higher NDF and ADF bound nitrogen than teff straw. Among the browse supplements, the crude protein (CP), potential degradability (PD) and effective degradability (ED) decreased in the order *S. sesban* > *C. palmensis* > *L. pallida* > *L. leucocephala*. Tannin levels decreased in the order *L. pallida* > *L. leucocephala* > *S. sesban* > *C. palmensis*

Table 1. Chemical composition and dry matter degradation characteristics of teff straw, *Leucaena leucocephala, Leucaena pallida, Chamaecytisus palmensis and Sesbania sesban.*

Species	OM	CP	NDF	NDFN	ADF	ADFN	Lignin	TC	W	c	PD	ED
Eragrostis tef	914	29	768	2	443	1	48	nd	96	1.4	794	273
L. leucocephala	917	153	414	35	262	21	144	12.4	280	3.3	626	448
L. pallida	903	195	377	41	220	20	102	29.6	286	2.5	713	448
C. palmensis	940	209	449	37	255	12	81	0.8	389	4.5	851	635
S. sesban	883	304	287	48	199	15	55	2.4	331	6.8	918	703

OM: organic matter (g kg^{-1} DM); CP: crude protein (g kg^{-1} DM); NDF: neutral detergent fibre (g kg^{-1} DM); NDFN: neutral detergent fibre bound nitrogen (g kg^{-1} NDF); ADF: acid detergent fibre (g kg^{-1} DM); ADFN: acid detergent fibre bound nitrogen (g kg^{-1} ADF); TC: Total soluble proanthocyanidins (g kg^{-1} DM); W: solubility (g kg^{-1} DM); c: rate of degradation (% h^{-1}); PD: potential degradability (g kg^{-1} DM); ED: effective degradability (g kg^{-1} DM); nd: not determined.

Table 2. The influence of graded levels of *L. leucocephala, L. pallida, C. palmensis* and *S. sesban* on intake of teff straw and live weight gain in sheep.

Source of		DMI (g $kg^{-0.75}$)						LWG		
supplement	Level (%)	Teff	Sup	Total	DOMI	SR	WT0	g d^{-1}	g g^{-1} sup	$gkg^{0.75}$
None (C)	0	55.2	0	55.2	24.6		19.9	-24.4		-27
L. leucocephala										
	15	53.2	7.4	60.6	27.2	-89	19.3	13.3	0.19	14
	30	49.5	14.4	63.9	29.8	121	19.4	25.9	0.19	27
	45	45.7	20.6	66.3	32.9	191	19.5	42.3	0.21	43
	60	39.2	26.5	65.7	32.7	312	19.4	56.1	0.21	55
L. pallida										
	15	49.9	7.4	57.3	28.1	337	19.6	8.3	0.12	09
	30	46.9	13.7	60.6	28.6	163	20.2	38.8	0.29	38
	45	42.8	20.4	63.1	30.0	372	19.5	60.6	0.31	59
	60	35.4	24.8	60.1	29.1	528	19.5	65.2	0.28	63
C. palmensis										
	15	52.6	7.2	59.8	27.5	34	19.4	6.5	0.10	07
	30	51.6	14.2	65.8	32.9	4	19.5	19.1	0.14	20
	45	50.5	20.5	71.0	37.5	-10	19.9	27.1	0.14	27
	60	46.7	26.8	73.6	38.4	134	19.4	35.1	0.13	36
S. sesban										
	15	56.6	7.3	63.9	30.0	-566	18.9	16.0	0.24	17
	30	49.4	14.0	63.4	31.0	63	19.4	40.5	0.30	41
	45	46.5	20.7	67.1	33.2	200	19.5	32.5	0.16	33
	60	45.0	25.7	70.6	36.1	231	19.5	30.8	0.12	32
SED (n=6)		2.52		2.79	1.35		1.0	9.1		
Statistical significance										
C vs browses		ns		***	***		ns	***		
Browses		***		***	***		ns	***		

Sup: supplement; DMI: dry matter intake; $kg^{0.75}$: metabolic weight; DOMI : digestible organic matter intake (g $kg^{-0.75}$); SR: substitution rate (g kg^{-1} sup); WT0: initial live weight (kg); LWG: live weight gain; ns: P>0.05; * P<0.05; **: P<0.01; ***: P<0.001.

Dry matter intake (DMI) and digestible organic matter intake (DOMI) increased (P<0.05) with increasing *level of L. leucocephala, C. palmensis* and *S. sesban*, and not in *L. pallida* (Table 2). A significant (P<0.05) decrease in teff straw intake was observed, as the level of supplement increased. Substitution rate (g teff subsituted by 1 kg browse) varied from *162 to 528* in *L. pallida*, *-89 to 312* in *L. leucocephala*, -566 to 231 in *S. sesban* and -10 to 134 in *C. palmensis* supplemented diets. Live weight gain increased significantly (P<0.01) with increasing level of supplementation. Significant (P<0.05) differences were observed among browse supplements and levels of supplementation. The animals fed the control diet lost weight (-24.4 g d^{-1}), while the supplemented ones gained weight in the range of 6.5 - 65.2 g d^{-1}. The maximum live

Table 3. Effect of supplementing teff straw with graded levels of browses on intake, digestibility, N excretion and retention in Ethiopian highland sheep (metabolism study).

Source of Supplement	level	Intake (g $kg^{-0.75}$ d^{-1})							Digestibility (g kg^{-1})					Excretion and retention[$]		
		Teff	Sup	Total	DOM	N	aan_M	aan_D	TDM	SDM	OM	NDF	N	FN	UN	NR
None (C)	0	47.5	0	47.5	22.9	0.29	0.25	0.11	486		488	451	146	0.25	0.09	-0.05
L. leucocephala																
	15	54.9	6.7	61.6	29.9	0.62	0.32	0.23	489	511	492	447	198	0.49	0.10	0.02
	30	53.8	13.5	67.3	33.9	0.89	0.36	0.33	508	593	511	485	387	0.55	0.17	0.17
	45	51.7	19.1	70.8	38.0	1.12	0.41	0.41	541	686	543	505	448	0.62	0.25	0.25
	60	44.9	24.2	69.1	37.2	1.29	0.40	0.48	541	644	544	489	497	0.65	0.30	0.34
L. pallida																
	15	53.7	7.0	60.7	32.2	0.60	0.34	0.22	534	900	537	511	252	0.45	0.11	0.04
	30	54.9	13.7	68.6	35.1	0.86	0.38	0.32	515	631	518	469	293	0.61	0.16	0.09
	45	46.6	19.1	65.7	33.9	1.02	0.36	0.38	520	601	522	443	323	0.69	0.25	0.08
	60	44.3	24.9	69.2	36.4	1.23	0.39	0.45	530	609	533	437	356	0.79	0.33	0.10
C. palmensis																
	15	49.6	7.1	56.7	28.1	0.50	0.30	0.18	498	580	502	494	275	0.36	0.08	0.05
	30	53.4	13.4	66.8	35.9	0.69	0.38	0.26	541	754	544	518	412	0.41	0.16	0.13
	45	50.6	18.8	69.4	39.6	0.83	0.42	0.31	572	804	574	507	447	0.46	0.24	0.13
	60	47.4	25.2	72.5	40.6	0.98	0.44	0.36	563	707	566	510	516	0.47	0.28	0.23
S. sesban																
	15	54.9	6.9	61.8	31.5	0.59	0.34	0.22	513	718	516	485	343	0.39	0.11	0.09
	30	52.3	12.3	64.6	34.8	0.77	0.37	0.29	538	757	540	513	504	0.38	0.21	0.18
	45	49.5	18.9	68.4	36.9	1.00	0.40	0.37	543	692	547	477	547	0.45	0.25	0.30
	60	45.2	25.3	70.5	39.4	1.21	0.42	0.45	564	702	566	500	563	0.53	0.27	0.41
SED (n=4)		2.61		2.89	2.17	0.04	0.002	0.013	19.2	70.2	19.3	50	43	0.05	0.03	0.05
Statistical significance																
C vs browses		ns		***	***	***	***	***	***		***	ns	***	***	***	***
Browses		ns		ns	ns	***	ns	***	ns	ns	ns	ns	***	***	ns	***

Sup: supplement; N: nitrogen; OM: organic matter; DOM: digestible organic matter; aan_M: amino acid nitrogen of microbial origin; aan_D: amino acid nitrogen of dietary origin; NDF: neutral detergent fibre; TDM: total dry matter digestibility; SDM: supplement dry matter digestibility; FN: faecal nitrogen (g $kg^{-0.75}$); UN: urinary nitrogen (g $kg^{-0.75}$); NR: nitrogen retention (g $kg^{-0.75}$); ns: P>0.05; *:P<0.05;**: P<0.01; ***: P<0.001; [$]: based on metabolic weight (g $kg^{-0.75}$).

weight gain (65.2 g d^{-1}) was observed in sheep fed a diet with 60% *L. pallida*. The optimum levels of browse supplementation in terms of LWG per g supplement were 45, 45, 30, 30% DM of total ration for *L. leucocephala, L. pallida, C. palmensis* and *S. sesban*, respectively.

Voluntary intake and digestibility values from the metabolism trial are given in Table 3. Supplementation increased significantly ($P<0.001$) DMI, DOMI, N intake and available amino acid. The supplemented animals differed significantly ($P<0.05$) in N intake, dietary amino acid N escaping rumen degradation, N digestibility, faecal N excretion and N retention. The digestibilities of total DM, OM, N and supplement DM increased significantly ($P<0.05$) with increasing level of supplementation. No significant ($P>0.05$) differences in DM, OM and NDF digestibility between the browse supplemented diets, however a significant ($P<0.05$) increase in N digestibility with increasing level of supplementation was observed. Faecal nitrogen, urinary nitrogen output and nitrogen retention increased significantly ($P<0.0001$) with level of supplementation.

Discussion

Voluntary DM intake or digestible organic matter intake did not show diminishing returns to increasing inclusion levels of browse, possibly because the basal feed was offered *ad libitum* and animals could adjust their intake. Other studies have shown that *Leucaena* increased voluntary DMI when included at the level of 0.4-0.5 of ration DM as a supplement to rice straw (Devendra 1983). The browses could have increased digestible organic matter intake by supplying the deficient nutrients in teff such as protein. One means by which protein supplementation improves performance of animals consuming low quality forages is through stimulation of voluntary forage intake (Kartchner, 1980; DelCurto et al., 1990).

Rumen fill is postulated to limit the intake of most forage-diets (Van Soest, 1982), and therefore higher levels of browse might be expected to displace more ruminal volume than comparable amounts of concentrate supplements, thus preventing maximum intake of the basal forage. The observed increase in total feed intake with increasing level of supplementation was due mainly to a substitution of teff straw with the browses, as shown by the increasing proportion of browse DM consumed. The differences in substitution rates among the browses may be related to relative rates of degradation of these supplements from the rumen (Bonsi et al., 1994). *S. sesban* and *C. palmensis* had higher rates of degradation than the *Leucaena* species (Table 1). Thus, increased rate of degradation increases the population of cellulolytic microbes and rapidly reducing the quantity of digestible browse in the rumen, thereby allowing more microbes to colonize and degrade the basal diet. The observed LWG in *S. sesban* and *C.*

palmensis supplementation could have been attributed to increased DM intake, as the animals fed teff straw only ate 55.2 g $kg^{-0.75}$ d^{-1}, while animals supplemented with *L. leucocephala, L. pallida, C. palmensis* and *S. sesban* ate a maximum of 66.3, 63.1, 73.6 and 70.6 g $kg^{-0.75}$ d^{-1}, respectively. Based on the tannin levels of the browses studies, it seems that browses low in tannin *(S. sesban, C. palmensis)* increased animal performance by enhancing DM intake while high tannin species (*L. pallida* and *L. leucocephala*) increased live weight gain by increasing the efficiency of utilization of the nutrients.

Most investigations of intake response to protein supplementation have been conducted with concentrate supplements. Previous research indicates that browses will support similar level of animal performance when fed to provide similar amounts of CP (Khalili and Varvikko, 1992; Varvikko and Khalili, 1993; Richards et al., 1994). In this study, animals on the control diet lost weight (-2.7 g $kg^{-0.75}$ d^{-1}), while the supplemented animals gained between 0.7 and 6.3 g $kg^{-0.75}$ d^{-1}. Although, teff straw intake was not increased by supplementation, a significant ($P<0.05$) increase in total DM intake with supplementation was observed. Legume supplementation of grass-only diets has been observed to improve animal performance (Chadhokar and Kantharaju, 1980; Reed et al., 1990). These responses have typically been attributed to the legume overcoming the depressing effect that the low N concentration grass has on intake (Minson and Milford, 1967), and by the legume providing ruminally degradable N (Van Eys et al., 1986) or ruminally escape N (Flores et al., 1979).

Data from this study indicate a strong relationship between LWG (Y; g d^{-1}) and the level of supplementation (X; g d^{-1}). The reduction in sum of squares of linear and quadratic relationships, tested against the mean square remaining after quadratic regression was significant ($P<0.05$) in all the browses. Quadratic equations for the browse species were:

L. leucocephala $Y = -21.78(3.80) + 0.46(0.07)X - 0.001(0.0002)X^2$ (RSD=9.84, R^2=0.89, $P<0.0001$);

L. pallida $Y = -23.66(6.28) + 0.52(0.12)X - 0.001(0.0005)X^2$ (RSD=16.12, R^2=0.78, $P<0.0001$);

C. palmensis $Y = -22.48(3.25) + 0.43(0.06)X - 0.001(0.0002)X^2$ (RSD=8.42, R^2=0.87, $P<0.0001$);

S. sesban $Y = -23.43(8.29) + 0.60(0.15)X - 0.002(0.0006)X^2$ (RSD=21.41, R^2=0.55, $P<0.0001$).

The F statistic for overall goodness of fit of the regression equations suggested that there was a statistically significant ($P<0.0001$) quadratic relationship between live weight and amount of supplement. The close agreement between the quadratic equation line and the data was reflected by the smaller value of the standard error of the estimate associated with the quadratic equation.

The effect of supplementation on apparent digestibility of the basal feed was assessed by calculating the apparent digestibility of the browse supplement by difference using digestibility of teff straw from the animals fed straw only. As the rumen environment was limited in nutrients such as nitrogen, it was likely teff straw digestibility differed in supplemented and unsupplemented animal groups. This could explain the observed increase in digestibility with increasing levels of supplementation. Bonsi et al., (1994) observed an apparent increase in teff straw digestibility with increasing levels of *Leucaena*.

There was a linear relationship between N retention and digestible organic matter intake (DOMI):

$$NR = -0.449\ (0.0839) + 0.0175\ (0.0024)DOMI \quad (RSD=0.10,\ R^2=0.48).$$

The regression equation of N balance on DOMI predicted a zero N retention at DOMI=26 g $kg^{-0.75}$, which was the same value as proposed by ARC (1980). Higher levels in sheep have been observed by Ketelaars and Tolkamp (1991) and Oosting (1993). An efficiency of amino acid deposition of 66% was realised from this experiment. This was estimated by regressing nitrogen retention against total microbial and dietary amino acid nitrogen (AAN):

$$NR = -0.298\ (0.054) + 0.66\ (0.076)AAN \quad (RSD=0.09,\ R^2=0.56).$$

The observed efficiency of amino acid deposition was in line with data from Rohr and Lebzien (1991) and Oosting (1993). ARC (1980) has adopted a value of 0.75, while the value 0.59 is adopted by AFRC (1992). Lower efficiency observed in this study was attributed to the age of the animals and the antinutritive factors which interfere with N utilization. The equation derived from this data implies a zero N balance at a total amino acid nitrogen of 0.445 g $kg^{-0.75}$. This is within the range of 0.380-0.620 g $kg^{-0.75}$ as proposed by Rohr and Lebzien (1991), Oosting et al. (1995) and Kamalzadeh (1996).

A number of experiments have been formulated to determine the optimum level of browse supplementation. Although weight changes were not measured in a number of these experiments, the increase in digestible DM intake may be predictive of improved weight gain. *Leucaena* supplements at a rate of 16% in DM were effective in converting a weight loss to a significant weight gain in both sheep and cattle (Wahyuni et al., 1982; ILCA, 1987). Higher levels of *Gliricidia* (33% in DM) were needed to convert a substantial weight loss in cattle to maintenance (Doyle et al., 1986). Devendra (1988) recommended that, when used as supplements, the optimum dietary level of fodder trees and shrubs should be about 30 to 50% of the ration on DM basis or 0.9 to 1.5 kg/100 kg body weight. Results from this study indicate an optimum level of 30 to 45% of the ration DM or 0.75 to 1.125 kg/100 kg body weight.

Acknowledgements

The authors wish to express their appreciation to the staff of ILRI Debre Zeit station for personnel and material support.

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Chapter 10

General discussion

General discussion

The nutritive value of browse depends on the voluntary intake of the feed consumed and the extent to which the quantity of dry matter eaten by the animal supplies dietary energy, proteins, minerals and vitamins. Much will depend therefore, on the actual quantity of feed eaten by the animal on a daily basis. As emphasized in Chapter 1, the prediction of nutritive value of browses is very complex and many factors that could contribute to the value of browses as animal feed have been identified (Table 1).

Table 1. Important factors to consider in predicting nutritive value of browses in the tropics.

Feed factors	Animal factors	Management and housing
Plant species	Animal species	Time of access to feed
Chemical composition	Breed	Frequency of feeding
Digestibility	Live weight	Sole diet vs. Supplementary diet
Degradability profiles	Growth	Grazing vs. Stall feeding
Rate of passage	Age	Mineral salts
Diet composition	Feeding history	Excess feeding to allow selection
Physical form	Body condition	
Palatability	Diseases	
Anti-nutritional factors	Learning	

Palatability in browses

With browses in general, the quantity eaten is likely to be small, partly because of sparsity, as well as the fact that they can seldomly be eaten exclusively due to their poor palatability. It has become clear in recent years that animals learn to associate the sensory properties of foods with the metabolic consequences of eating those foods. Most of the herbivores are colour blind although their eyes possess cones. Temporary covering of the eyes didn't interfere with the preference for herbage species by grazing sheep (Arnold, 1966a, 1966b) suggesting that they use smell, taste and tactile stimuli to a great extent to discriminate between different plant species.

Significant differences were observed with the palatability and dry matter intake among browse species (Chapter 2). For some of the browses, intake decreased with time over the 12-day experimental period suggesting that animals could have developed anti-feeding reflex due to factors such as taste, smell, volatile compounds or astringency, which could elicit the observed response. Phenolics, alkaloids, tannins and aromatic compounds are some chemical compounds known to alter palatability

(Marten, 1973) through the above mechanisms. Thus, the choice of trial length is important. An erratic behaviour on preference was observed on day 1, and within the next 4 days preference rating was developed. Linear regression, correlation analysis, palatability ranking with time indicated that a period of at least 5 days was appropriate if palatability was used to predict long-term intake of browses. Periods less than 5 days lead to highly variable results while 5 to 12 days could be equally useful. It was concluded that palatability trials of less than five days with sheep should be highly discouraged.

Plant factors that influence browse palatability to animals are species, intra-specific variation, chemical composition, morphology or physical traits, succulence or maturation, availability in non-controlled situations and physical form of forage (Marten, 1978). The probable cause of low palatability of some of the browses was attributed to these factors. For example, *Calliandra calothyrsus* (Kaitho, 1992; Palmer and Schlink, 1992) and *Chamaecytisus palmensis* (Varvikko and Khalili, 1993; Varvikko et al., 1992; Umunna et al., 1995) have been reported to have poor palatability in dry form in both sheep and cattle, but had high palatability when offered in the wilted form (Kaitho et al., 1997).

Effects of animal species and form of browse

Chapter 3 examined the effects of form of browse (wilted or dry) and animal species (sheep and goats) in order to identify browses that are palatable in either of the forms and match these with the appropriate animal. Both sheep and goats showed adaptation to the browses with time. Palatability indices derived from day 1 were poorly correlated to indices on subsequent days. This confirmed the assertion made in Chapter 2 that preference on first day was erratic and preference rating was developed within the first 4 days. The period of 5 to 8 days was ideal for palatability assessment of browses in sheep and goats. This concured with the previous observations of by Salem et al. (1994). Browses with good nutritive value such as *L. leucocephala*, *C. palmensis* and *A. persiciflora* had consistently high intake and palatability irrespective of the form offered to both sheep and goats. Strong odours and tannins implicated as causes of poor palatability in some of the browse species such as *Albizia schimpheriana, Samanea saman* and *Acacia polyacantha* were reduced by drying, leading to an improvement in palatability.

The form (dry or wilted) did not affect the palatability indices in this study. However, animal and browse species variations were observed. *Acacia nilotica* and *Acacia persiciflora* were more preferred in the wilted than in the dry form by both sheep and goats while the reverse was observed for *A. polyacantha, A. saligna, A. schimpheriana* and *Entada abyssinica*. Correlation and regression analysis gave a poor predictability

of palatability for sheep using goats' palatability indices. On the average, palatability indices for goats were more than double those of sheep. The differences were attributed to the ability of goats to secret proline-rich protein in saliva (Robbins et al. 1987) and the high affinity of proline-rich protein for tannins, which could have reduced astringency. The variation in anti-nutritional effects of browses in different animal species may arise as a result of the ability of certain animals to secrete trichloroacetic acid soluble proline-rich protein. These proteins constitute the first line of defence against ingested tannins (Mehansho et al., 1987).

Choice of palatability method

The palatability method reported in Chapters 2 and 3 is suitable for evaluating the palatability of a large number of browses and other forages under stall feeding condition. Compared to conventional palatability methods (oesophageal fistula technique, rumen content analysis and faecal analysis) this method was easier, cheaper, less labourious and more convenient for screening a wide range of forages. Beside providing palatability indices, this method provided information on dry matter intake which was an advantage over the cafeteria method. These two studies showed that short palatability trials should be discouraged because animals show adaptation to feeds with time. If palatability is expected to predict longer term intake, a period of 5 to 8 days should be allowed.

Interrelationship with degradability, gas production and chemical composition

In Chapter 4, an attempt to establish any interrelationships among gas production, dry matter degradation and/or chemical composition attributes with palatability as well as examine the influence of chemical composition on gas production and dry matter degradation was made. The browses had widely varying effective degradabilities (217-754 g kg^{-1} DM) and total gas productions (45-130.5 ml g^{-1} OM). The data on degradability and gas production indicated a possible tannin-induced depression for a number of browse species such as *Acacia dolichocephala, Acacia hockii, Acacia melanoxylon, Acacia polyacantha* and *Flemingia macrophyla*. The presence of tannins and its depressing effect on DM and N degradability had been recorded in *Calliandra calothyrsus* (Palmer and Schlink, 1992) and a number of *Acacia* species (Woodward and Reed, 1989). The inverse relationship between tannin levels in forages and palatability, voluntary intake, digestibility or N retention in some mammalian herbivores is well established (Robbins et al., 1987; Silanikove et al., 1994; Silanikove et al., 1996).

Differences in solubility and potential degradability among the browses were primarily attributed to their NDF and N concentrations. Correlation analysis showed that

NDF, ADF and lignin negatively affected DM degradation and gas production. This was in accordance with previous reports on the negative effects of NDF, ADF and lignin (Minson, 1982; Nsahlai et al., 1994; Nsahlai et al., 1995) on forage digestibility. The strong relationship between DM and N degradation characteristics revealed the possibility of predicting N degradation using DM degradation characteristics (Chapter 5). Chemical constituents accounted for some variation in N degradability characteristics but were inadequate predictors on their own. However, when used in combination with DM characteristics, there was an increase in the amount of predictable variation in N degradation characteristics. The strong negative (NDF, ADF, lignin) and positive (N, NDFN, PD, AG) relationships between palatability and chemical constituents revealed the possibility of predicting palatability or DM intake. Although the coefficients of determination between palatability, DM intake and other attributes studied were low, they were however modest and the parameters can be used alongside desirable agronomic attributes (e.g. persistence, perenniality during the dry season, high foliage yield and rapid regrowth ability) to select and classify potential fodder materials into a few categories. A detailed study of a few members of each class could then provide specific recommendations for that particular class.

The mean palatability index (Chapter 2) was used to fragment the browses into cluster groups. Representative members from this classification were used in the next experiment (Chapter 3). The cluster groups developed in Chapter 2 and Chapter 3 were similar. However, regardless of the re-classification variables (chemical composition, gas production parameters, degradability coefficients or their combinations) used (Chapter 4), the level of misclassification were rather high ranging from 33.3 to 88.9%. Thus, chemical constituents, degradability and microbial gas production attributes are inadequate in clustering browses into similar classes as palatability. The reason may be due to the fact that palatability is determined by additional factors such as taste, odour and texture, some of which have no influence on either of the above predictors.

Rumen and intestinal protein digestibility

There are reports suggesting that some forage proteins are degraded to a large degree in the rumen (Ulyatt et al., 1975), and that ruminants fed such forages have responded positively to supplementation with slowly degraded proteins. Van Eys et al. (1986) associated the increased weight gain observed in goats supplemented with *Gliricidia, Leucaena* or *Sesbania* with the quantity of rumen degradable protein in the legumes and its effect on microbial protein production. In Chapter 5, tannin rich browses such as *Acacia hockii, Acacia melanoxylon, Acacia venosa, Casuarina cunninghamiana, Casuarina glauca, Entada abyssinica* and *Flemingia macrophylla* had high rumen bypass N, but poor intestinal digestibility of the bypass protein. The latter effect was

linked to the ability of tannins to bind with feed proteins and enzymes thus reducing their digestibility (Cheeke and Palo, 1995). Conversely, browses such as *Sesbania* species and *Acacia nilotica* containing low tannins underwent rapid and extensive degradation in the rumen (Bonsi et al., 1994; Umunna et al., 1995) leading to low bypass N. Browse species evaluated in this trial provided moderate levels of bypass N with apparent digestibility ranging from -22 to 76% which was definitely lower than what was reported for temperate feeds (van Bruchem et al., 1989). Intestinal digestibility of bypass N is one of the important parameters used in the new protein evaluating system for ruminants (Frydrych, 1992).

Mobile nylon bag and pepsin/pancreatin in vitro methods

This study further examined whether an *in vitro* method could be used to predict the digestibility of rumen undegradable protein. The pepsin/pancreatin *in vitro* method (IV) accounted for over 79% of the variations in mobile nylon bag method (MNB). Judging from the intercept of the regression relationship, the IV method overestimated post ruminal N digestibility relative to the MNB method. Similar observations have been made by van Straalen et al. (1993). The accountable variations were further improved when either nitrogen, acid detergent fibre, total phenolics and neutral detergent fibre bound tannin levels in browses were included. Based on the observations reported in Chapter 5, it was concluded that the nitrogen content of browses *per se* does not fully account for their nutritive value as protein supplements. Factors such as nitrogen degradability in the rumen and digestibility of the bypass nitrogen are of paramount importance.

Anti-nutritional factors in browses

Plants have co-evolved with predator populations of bacteria, insects, fungi and grazing animal, and have developed defence mechanisms which assist their survival. Browses often have thorns, fibrous foliage and growth habits which protect the crown of the tree from defoliation. Beside these physical protection mechanisms, many of the browse species produce secondary compounds which function as defence against bacterial, viral, fungal and environmental stresses (Salunkhe et al., 1990). These secondary compounds may be bitter tasting, poisonous, or have an offensive odour, or have anti-nutritional effects to predators. The three main classes of secondary compounds are nitrogen containing compounds, terpenoids and phenolics. Phenolics have an overwhelmingly diverse group of structures and are more widespread. Tannins are polymers whose monomeric units are phenols.

Effects of tannin on nitrogen metabolism and animal performance

The value of forages as supplements depends mainly on their capacity to provide the nutrients that are deficient in the basal diet. This includes their ability to provide the essential nutrients to the rumen microbial population and/or critical nutrients to meet the host animal's requirements and increase the efficiency of feed utilization (Elliot and McMeniman, 1987). Thus basal cereals straws and poor quality pastures alone supply a deficient diet which can respond to supplementation with browses, probably as a consequence of improved N supply in the rumen (Chapter 6). Recommended use of tannin-rich forages is complicated by the effects of stage of maturity, local environment (Barry and Forss 1983) and drying procedures (Price et al., 1979) on the phenolic content. A considerable variation in the level of phenolics was observed in this study, which depended not only on browse species, but also on the method of analysis.

Review of the literature on this subject revealed that current tannin assay methods gave results that are poorly related to nutritional effects because the chemical properties that are involved in the reactivity of polyphenols in colorimetric and/or precipitation assays may differ from the properties that underlie their nutritional or toxic effect (Reed 1995). Tannin chemistry between plant species may differ significantly and may be responsible for the varied effects on livestock. In Chapter 6, live weight gain was higher in *Leucaena* (with higher levels of tannins) than lablab, tagasaste, low tannin *Sesbania* species supplemented animals. This could be due to the differences in the chemical, biochemical nature, variation in molecular weight and nature of interflavonoid linkage of tannins (Kumar, 1983; Hagerman et al., 1992).

Using the data on *Sesbania* species and assuming the variations in chemical composition was mainly caused by different tannin levels, increasing level of tannins was associated with an increase in animal responses (dry matter intake, live weight gain) up to a certain point followed by a decline. Increasing level of tannins was also associated with an increase in dry matter and nitrogen escaping rumen degradation and decrease in rate of degradation (Chapter 7). Fibre (NDF) digestibility was depressed by supplementation with browses rich in tannin, however there is a problem in interpreting NDF digestibility in this case, because condensed tannins complex with other dietary components and appear as faecal NDF, which biases the estimation of true-NDF digestibility (Reed 1986). Tannins could also depress digestibility by inhibiting microbial enzymes (Waage et al. 1984) and by forming indigestible complexes with protein and carbohydrates (Hagerman 1989). It is possible that ruminants fed high-tannin legumes have an overall shortage of rumen-degradable N and that it was this insufficiency which partly impaired the digestibility of structural carbohydrates (D'Mello, 1992). The implication of these findings was that tannins protect protein and fermentable carbohydrates against ruminal fermentation and consequently increase the supply of

high-quality nutrients entering the duodenum. Browse species with low tannins and high N degradability provide high levels of rumen ammonia, much of which was wasted by excretion as urinary urea. Species which contain moderate levels of tannins and with intermediate rates of degradation provided adequate levels of both rumen degradable protein and bypass protein, and were more effective sources of supplemental protein (Chapter 7). Supplements with high degradation rates had low estimated escape protein, high N digestibility and had probably poor synchronization pattern leading to loss of N as ammonia. Forages with a high proportion of escape protein were used more efficiently (Buxton, 1996).

Increasing levels of tannins was also associated with increasing levels of faecal N and decreasing levels of urinary N. This tendency agreed with the findings of Woodward and Reed (1989) and Wiegand et al. (1995). With low tannin forages, excessive amounts of nitrogen may be excreted as urea in urine, in which case a large percentage can be lost to the environment. The implication of the shift of N excretion from urine to faeces is important especially to poor resource farmers, natural resource management and sustainability. The advantages of tannin-complexing dietary nutrients, especially protein, are obvious for the smallholder, who to a large extent depends on tannin-rich forages for protein supply to his stock, and on faeces to improve the soil fertility for his crops.

Effect of tannins on microbial protein synthesis

Correcting dietary protein deficiency can have two effects in ruminants. It could increase the microbial degradation of food in the rumen and/or improve the animal's metabolic capacity to use energy, both of which lead to an increase in the voluntary intake of digestible organic matter and in animal performance. Metabolizable protein requirements of ruminants are met primarily from rumen microbial protein and from dietary protein that escapes the rumen undegraded (Robinson et al., 1991). This was clearly evident in the estimated microbial protein synthesis and nitrogen retention of the animals supplemented with the browses irrespective of the browse tannin levels and the live weight changes (Chapter 7). Supplementation increased microbial protein synthesis in line with observations made by Oosting (1993). The high N content of the browses makes them good protein supplements and when fed at the level of 180 g per day supplied moderate levels of rumen-available N that could effectively be trapped for microbial synthesis. The efficiency of microbial N synthesis could be increased by supplementing with modest amounts a complementary energy substrates (Nsahlai and Umunna, 1996). In conclusion, the browse supplements had varied effects on the utilization of dietary protein and this was probably influenced by different types and concentration of phenolics. Supplementation increased nitrogen retention about 9-fold

(0.3 vs 2.7).The results from this study indicated that Tannin-rich forages are suitable protein sources, as long as the negative effects of tannins of increasing output of faecal N is less than their positive effect on reducing urinary-N loss. The positive responses obtained were attributed to the abilities of the browse supplements to overcome a nitrogen deficiency in the basal diet by providing more ruminally degradable N and/or estimated escape N.

Comparative value of browses to sheep and goats

Among species of ruminants, there are differences in susceptibility to plant toxins. Sheep are considered more resistant to alkaloids than cattle (Cheeke, 1988) and in numerous other instances, goats are more resistant than sheep to poisonous plants (Cheeke and Shull, 1985; Kellerman et al., 1988). To a considerable extent, these differences among ruminants are a reflection of feeding strategy and the nature of diet upon which the species evolved. Cattle evolved as grazing animals on grasslands, goats are browsing animals, consuming non-grass herbaceous plants as a major component of their natural diet, whereas sheep are intermediate (Van Soest, 1994).

The sheep and goats exhibited different preferences for the browses as indicated by the contribution of the browse to the diet (Chapter 8). Goats had higher nutrient digestibilities than sheep. Anatomically, the alimentary tract of goats is more like that of a browser whereas that of sheep is like that of a grazer (Hofmann, 1983). Goats have a relatively larger rumen volume for their size than sheep when fed on the same diet and a similar rate of passage of both the liquid and particulate phases of the digesta (Domingue et al., 1991). Sheep and goats appear to digest high digestibility forages to a similar extent, but goats tend to be more efficient at digesting low digestibility diets (Domingue et al., 1991). Goats appear to be able to digest forages containing secondary compounds more extensively than sheep (McCabe and Barry, 1988). This may result from the differential adaptation of goats' rumen microflora (Giad et al., 1980) and salivary proteins (Provenza and Malechek, 1984; Robbins et al., 1987) which nullify the effect of digestion-inhibiting tannins present in many browse species.

Effects of browses on reproduction

Nutritional deficiency is usually caused by general "underfeeding" with poor quality roughages. Animals fed under these conditions tend to be retarded in body development and the sexual organs share in this retardation. The above effects on reproduction are usually directed at the anterior pituitary gland, which fails to secrete enough gonadotropins to stimulate the testis to produce testosterone and semen (Asdell, 1955). The provision of protein, energy and mineral supplements is a

prerequisite for a successful management to good reproductive performance of animals (Topps, 1977). Rams receiving high energy diets were better in terms of body condition, semen production, scrotal circumference and gonadotropin output than those on low energy diets (Alkass and Bryant, 1982).

The study described in Chapter 8 confirmed earlier reports that have indicated a significant association between plane of nutrition, body weight and scrotal growth (Alkass and Bryant, 1982; Rekwot et al., 1988; Mukasa-Mugerwa and Ezaz, 1992). Scrotal circumference measurements correlated well with live weight in this study. Sperm production in rams is related to testicular size (Cameron et al., 1984) and fertility can be determined by changes in the size of testicles. *Leucaena* supplementation had a positive effect on live weight gain and reproduction, and the response was better on animals supplemented with the higher level. The converse was true for *Sesbania* supplementation. Animals supplemented with the higher level of *Leucaena pallida* exhibited the highest growth rate and scrotal circumference changes although, shedding of fleece was noticed after 80 days in both sheep and goats. *Leucaena* contains mimosine and the accumulation of the rumen by-product (DHP) leads to goitre, listlessness, loss of appetite, excess salivation, hair loss and loss of weight. However, this effect seems to occur if *Leucaena* constitutes a high proportion of the animal's diet (>30%) and when the animals are maintained on such a diet for an extended period. Prolonged uninterrupted intake of *Sesbania sesban* had a negative effect on live weight gain and scrotal circumference changes in both sheep and goats. This could be attributed to phytochemical(s) such as phytoestrogens. Phytochemicals have a regulatory role in reproduction of small herbivores such as meadow voles and lemmings (microtine rodents) (Berger et al., 1981; Sanders et al., 1981) and have been attributed to the adverse effects on reproduction of sheep grazing subterranean clover (Adams, 1989). The implications of these findings is that there may be some browse species which could have a negative effect on reproduction, and therefore the promising browse species should be further tested for their effects on reproduction before their full integration into the farming system.

Browses as supplements to low quality roughages

Most investigations of intake response to protein supplementation have been conducted with concentrate supplements. Previous research indicates that browses will support a similar level of animal performance when fed to provide similar amounts of CP (Khalili and Varvikko, 1992; Varvikko and Khalili, 1993; Richards et al., 1994). In Chapters 6, 7 and 9, animals on the control diet lost weight, while the supplemented animals gained weight. Although the basal diet (teff straw) intake in these studies was not increased by supplementation, a significant ($P<0.05$) increase in total DM intake with

supplementation was observed. Rumen fill is postulated as one of the factors that can limit the intake of most forage-diets (Van Soest, 1982). Therefore, higher levels of browse might be expected to displace more ruminal volume than comparable amounts of concentrate supplements, because browses are bulky and have lower energy/protein density. The observed increase in total feed intake with increasing level of supplementation (Chapter 9) was due mainly to a substitution of basal diet with the browses, as shown by the increasing proportion of browse dry matter consumed. Digestibility increased with the level of browse supplementation and consumption, leading to a substantial increase in digestible dry matter intake.

Optimum levels of browse supplementation

The differences in substitution rates among the browses may be related to relative rates of degradation of these supplements from the rumen (Bonsi et al., 1994). Browses with high rates of degradation tend to elicit lower substitution rates than slow degrading ones. Thus, increased rate of degradation could increase the population of cellulolytic microbes which could rapidly reduce the quantity of digestible browse in the rumen, thereby allowing more microbes to colonize and degrade the basal diet. Based on the tannin levels of the browses studied, it seemed that low-tannin browses *(Sesbania sesban, Chamaecytisus palmensis)* increased animal performance by enhancing dry matter intake while higher tannin species (*Leucaena pallida* and *Leucaena leucocephala*) increased live weight gain by increasing the efficiency of utilization of the nutrients. Data from this study indicated a strong relationship between live weight gain and the level of supplementation.

Supplementation increased the whole tract apparent digestibility mainly by increasing basal diet digestibility. However, this trend was not observed when browse digestibility was determined by difference. As the rumen environment is limited in nutrients such as nitrogen, it is likely that basal diet digestibility differs in supplemented and un-supplemented animal groups. This could explain the observed apparent increase in supplement digestibility with increasing levels of supplementation.

A number of experiments have been formulated to determine the optimum level of browse supplementation. *Leucaena* supplements at a rate of 16% in DM were effective in converting a weight loss to a significant weight gain in both sheep and cattle (Wahyuni et al., 1982). Higher levels of *Gliricidia* (33% in DM) were needed to convert a substantial weight loss in cattle to maintenance (Doyle et al., 1986). Devendra (1988) recommended that, when used as supplements, the optimum dietary level of fodder trees and shrubs should be about 30 to 50% of the ration on dry matter basis or 0.9 to 1.5 kg/100 kg body weight. Results from this study indicate an optimum level of 30 to

45% of the ration dry matter or 0.75 to 1.125 kg/100 kg body weight.

Feed requirements to be met by browses

Fibrous cereal and crop residues as sole diet don't usually meet animal maintenance requirements. To enhance production, supplementary feeds are needed that contain protein which is at least partly degraded in the rumen (RDP) to ensure that rumen ammonia concentration can support microbial growth (Hoover, 1986). On average, organic matter degradation in the rumen was about 70% of the whole tract digestion, while about 200 g microbial protein was synthesized per kg rumen degraded organic matter (RDOM) (van Bruchem et al., 1993). Microbial protein consists of about 75% of true protein with digestibility in the small intestine of approximately 85%. Hence, small intestinal available amino acid N (SI-AAN) from microbial origin was equivalent to about 15 g SI-AAN kg^{-1} DOMI. This was considered sufficient to cover maintenance requirements. For 20 kg sheep fed teff straw diets, maintenance requirements for energy and protein were approximated at 246 g DOM (26 g DOMI $kg^{-0.75}$) and 4.2 g SI-AAN (0.445 g SI-AAN $kg^{-0.75}$), respectively (Chapter 9). This was within the range as proposed by ARC (1984), Rohr and Lebzien (1991), Kamalzadeh (1996) and Oosting et al. (1995).

According to McDonald et al. (1988) sheep at half of their mature weight deposit about 325 g fat and 163 g protein per kg gain. With an efficiency of metabolisable energy to net energy of 0.70-0.75 and 0.50-0.55 for fat and protein respectively, and for SI-AAN into lean meat AAN of 0.5-0.55, about 30 g SI-AAN was required per kg DOMI (ARC, 1984; Oosting, 1993). With a daily live weight gain of 47 g d^{-1} (5 g $kg^{-0.75}$), the whole diet DOMI was approximately 340 g (36 g $kg^{-0.75}$) which was equivalent to 236 g RDOM (25 g RDOM $kg^{-0.75}$) and would require 47 g RDP (5 g RDP $kg^{-0.75}$). Assuming the basal feed provided 217 g (23 g $kg^{-0.75}$) of the DOMI, then 17 g RDP for a 20 kg sheep need to be supplied by the supplement. With an optimal level of supplementation of about 180 g supplement (19 g $kg^{-0.75}$), the required amount of RDP will be supplied by a browse with 94 g RDP kg^{-1} DM. Browses species with adequate levels of RDP to meet these requirements were *Acacia nilotica, Acacia polyacantha, Acacia sieberiana, Albizia schimperiana, Atriplex numularia, Atriplex rhagodiodes, Chamaecytisus palmensis, Enterolobium cyclocarpum, Erythrina burana, Erthrina bentipoeme, Erthrina abyssinica, Gliricidia sepium, Moringa stenopetala, Samanea saman, Sesbania goetzei, Sesbania sesban* and *Sesbania sesban* var bicolor.

At a level of 10 g DOMI $kg^{-0.75}$ above maintenance energy requirements, 0.3 g SI-AAN $kg^{-0.75}$ was needed for growth (De Jong and van Bruchem, 1993). This was 0.15 g SI-AAN $kg^{-0.75}$ or about 1 g IDP $kg^{-0.75}$ more than SI-AAN available from rumen microbial protein. With a forage supplement of 180 g (19 g $kg^{-0.75}$), on dry matter basis,

this will be about 53 g IDP kg^{-1} DM. This criteria was met by *Acacia horrida, Acacia microbotrya, Acacia nilotica, Acacia polyacantha, Acacia saligna, Calliandra calothyrsus, Chamaecytisus palmensis, Gliricidia sepium, Leucaena leucocephala, Leucaena pallida, Sesbania goetzei, Sesbania sesban* and *Sesbania sesban* var bicolor.

Domestic animals utilize trees and shrubs both as browse in situ and "cut and carried" branches in the stall. On rangelands animals have the advantage of selecting from a wide range of choices of browse and obtaining a high quality feed. A few of the browses such as *Chamaecytisus palmensis, Gliricidia sepium* and *Sesbania species* studied had adequate levels of RDP and IDP. Browse species with high IDP such as *Calliandra calothyrsus* could be fed mixed with browses with high RDP and low IDP. Consumption of various type of forage reduces chances of poisoning (Dicko and Sinkena, 1992) and complementation may occur. Le Houerou (1991) reported that consumption of mixed shrubs was higher than that of a single species. Farmers currently overcome and reduce problems of effects on animals by feeding mixtures of the browses with or without sun drying.

Conclusions

The palatability method developed in this study is suitable for evaluating palatability of a large numbers of browses and other forages under stall feeding condition. Short palatability trials should be highly discouraged because animals show adaptation to feeds with time. If palatability is done to predict long term intake a period of 5 to 8 days should be allowed. Classification of browses using either chemical composition, degradability or gas production led to different cluster groups than when palatability was used. The *in vitro* N digestibility when used in combination with N, ADF fibre, total phenolics or neutral detergent fibre bound tannin levels in browses could be used to predict digestibility of ruminally undegradable N. Tannin had beneficial attributes at low levels and may posses detrimental effects at high levels. Some of the browse such as *Sesbania* species had a negative effects on reproduction. The optimum level of browse supplementation determined in this study was 30 to 45% of the ration dry matter.

Implications

The work described in this thesis was aimed at developing indices that could be used to predict nutritive value of browses as supplements to poor quality roughage basal diets. The palatability method described and evaluated in this thesis may be used in practice as a tool to segregate a large number of browse species into similar groups, whose representative members of each group can be studied in depth. Classification

of browses using palatability has advantages over use of degradation, gas production or chemical composition because some of the inherent animal and plant factors are taken into account. The digestibility of rumen undegradable N can be estimated by the pepsin/pancreatin *in vitro* method. Further development of standard methods of quantifying and assessment of biological effects of tannins and other anti-nutritional factors needs attention as the current methods are inadequate. Long term studies of the superior browse species are necessary as some of the species' negative effects are only observed in long term feeding trials.

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Summary

In tropical and subtropical regions, pasture grasses and cereal residues are frequently low in protein and therefore cannot support high levels of ruminant animal production. The low quality and the seasonal nature of the forage supply, together with the low intake by the animals and the poor digestibility of the forage, are major factors contributing to the low productivity of ruminant animals. Legume supplementation of grass/cereal residues diets with <7% crude protein, has been shown to increase dry matter intake and improve animal performance. Trees and shrubs (browse) are a group of feed supplements that are currently not fully exploited in livestock feeding especially in the smallholder systems, because the mode of utilization has not been fully understood.

Browses are more important than simply being a source of feeds. In many situations, they form part of complex interactions between soil, plants and animals. They help to balance the plant-animal-soil ecosystem. The foliages of some are used as vegetables by humans while the roots, bark or stem and leaves of others are used for medicinal purposes. In ruminant nutrition they provide rumen degradable nitrogen and/or by-pass nitrogen, digestible energy and minerals when used as either supplements or as sole feed.

Many browse species have been documented as useful animal fodders. Although not all browses are legumes, more than 200 species of leguminous trees are reported to be used for fodder, with most species tropical or sub-tropical in origin. The most commonly used species come from the genera *Acacia, Albizia, Calliandra, Desmanthus, Desmodium, Gliricidia, Leucaena, Prosopis and Sesbania.* Although there is considerable diversity, past research and development activities have tended to work on a very narrow range of the available germplasm, in which *Leucaena leucocephala and Gliricidia sepium* in Asia and Africa and *Erythrina poeppigiana* in Latin America have been prominent. This is unfortunate as the narrower focus has tended to overlook many other valuable trees like *Acacia* species.

Browses have nutritional diversity in terms of chemical composition and their effect on rumen microbes or the host animal. These nutritional differences could be attributed to plant age, plant part, harvesting regimen, season, location, concentration of antinutritional factors (secondary compounds) and form (fresh or dried) of presentation. These factors determine their chemical composition, palatability, intake, the extent and rate of degradation, digestibility and nutrient utilization by ruminants fed predominantly low quality roughages.

There is no simple predictor of the quality of browse foliage, as chemical composition alone is an inadequate indicator of nutritive value. Therefore, the main objective of this thesis was to develop indices that could be used to predict nutritive value of browses as protein supplements to poor quality roughage basal diets. In an attempt to develop these indices, issues related to establishing an experimental procedure for screening large number of browse species in feeding trials, the choice of animal species to be used in these trials and the proportion of browse in the diet were addressed.

Chapter 1 reviews browse utilization and constraints to their efficient utilization. The nutritive value of a feed depends on the voluntary intake and the extent to which the quantity of dry matter eaten by the animal supplies dietary energy, proteins, minerals and vitamins. Much will depend therefore on the actual quantity of feed eaten by the animal on a daily basis. With browse legumes, the quantity eaten is likely to be relatively small, partly because of the sparsity of feeds, as well as the fact that the legumes are seldom eaten exclusively. Palatability is as important as digestibility in determining voluntary intake of browses since many of them are

endowed with anti-nutritional factors which are known to affect palatability. Palatability of browses has been related to both physical characteristics (hairiness, bulk density) and the presence of compounds which affect taste and appetite (volatile oils, soluble carbohydrates, anti-nutritional factors).

A number of trials have been carried out to study palatability of browses, however conventional methods commonly used to assess classic forage preference (oesophageal fistula technique, stomach content analysis and faecal analysis) are not convenient for screening a wide range of browses, as they are laborious, costly and complicated. A method based on direct feeding observation and measurement of intake of plant species in stall feeding experiments was developed in Chapter 2 using 40 browse species. Choice of trial length was important when observations were made on direct feeding. Palatability assessment for 5-8 days gave the most accurate prediction of intake and stable relative palatability ranking by sheep. The 40 browse species were segregated into 4 clusters based on the palatability indices developed. In Chapter 3, representative members from each cluster developed above were selected to validate the palatability method as well as to find out the effects of form (wilted or dried) and animal species (sheep or goats). Goats had higher preference for browse than sheep. The form of feed (wilted or dry) did not affect palatability index. The indices also depended on previous cluster groups. The results from this study indicated that the palatability method developed was suitable for assessing browse palatability.

A wide range of browse species are being assessed agronomically especially with respect to stage of cutting and for feed value. In addition to animal response, both nylon bag degradation and fermentation characteristics of these browses are being studied. Chapter 4 describes the inter-relationships among palatability and chemical composition, gas production and rumen degradation parameters in an attempt to find out which among the procedures could predict palatability and thus intake. Palatability and dry matter intake (DMI) were negatively correlated to neutral detergent fibre (NDF), acid detergent fibre (ADF), and lignin, and were positively related to neutral detergent fibre bound nitrogen (NDFN). The phenolic components were more related to dry matter degradation and gas production than to palatability and DMI. Lignin was negatively correlated to potential degradability and gas production. NDFN and gas production had positive contribution to both palatability and DMI. It was concluded that chemical constituents such as N, NDF, NDFN, ADF and lignin are essential in describing the nutritive value of browses. Cluster groups developed using palatability as classifying variable were different than the ones formed by using either chemical composition attributes, gas production parameters or DM degradation characteristics. Therefore, attempts should be made to determine palatability of the browse species that are being screened for their nutritive value.

In all-forage or forage based diets, protein quality of each dietary component is important in evaluating responses to supplementation. The new systems of protein evaluation partition feedstuff nitrogen into the amount degraded in the rumen and that which escapes ruminal degradation. The mobile nylon bag (MNB) and pepsin/pancreatin *in vitro* methods (IV) were used to determine the digestibility of rumen undegradable feed protein (Chapter 5). Browse species with high tannin content such as *Acacia hockii, Acacia horrida, Acacia melanoxylon, Acacia persiciflora, Acacia salicina, Acacia saligna* and *Flemingia macrophylla* had high rumen by-pass and a low digestibility of the by-pass protein (ND). *Acacia sieberiana, Chamaecytisus palmensis, Erythrina spp, Gliricidia sepium, Samanea saman* and *Enterolobium cyclocarpum* had high by-pass protein and with a high proportion of the by-pass protein being digestible. The ND measured with the MNB were significantly lower than by the IV method. The R^2 from the

correlation analysis was 0.89 indicating a much stronger relationship between these two methods. The intercept of the linear relationship obtained between MNB and IV was different from zero while the slope was not different from unity, implying that the IV overestimated MNB. Multiple regression analysis suggested that this can be corrected by adjusting the IV values by N, ADF or total phenolic levels in browses. Therefore, the IV method is good for estimating digestibility of ruminally undegradable N, and hence its use would considerably reduce the need for delicate surgery and the elaborate procedures involving the MNB technique.

Tannins are sometimes accredited with beneficial attributes in ruminant nutrition by virtue of their capacity to suppress bloat, reduce the effects of intestinal nematodes on productivity, and to prevent excessive degradation of high-quality leaf protein in the rumen and consequently increasing the supply of high-quality protein entering the duodenum. Chapter 6 and 7 describes the response of sheep consuming teff straw and supplemented with foliage of *Dolichos lablab*, *Chamaecytisus palmensis*), *Leucaena leucocephala*, *Sesbania goetzei,* and six accessions of *Sesbania sesban* (S1190, S1198, S2024, S10865, S15019 and S15036) with varying tannin levels. Supplementation significantly increased total DMI and live weight gain (LWG). The animals on teff straw only lost weight (-1.9 g $kg^{-0.75}$), while the supplemented animals gained daily between 2.9 and 4.4 g $kg^{-0.75}$. Leucaena supplementation promoted higher ($P<0.05$) LWG than Lablab, S1190 and Goetzei. With increasing tannin levels (among Sesbania accessions), there was an increase (S1190<S1198<S10865<S15019) followed by a decrease (S2024>S15036>goetzei) in LWG. Increasing levels of tannins were also associated with a general increase in escape by-pass protein and faecal N, and a decrease in urinary N. Supplementation increased faecal N output significantly as well as the N retention. The estimated rumen degradable protein (supplements) varied from 482 to 744 g kg^{-1} protein, while intestine digestible protein and the undegradable protein varied from 140 to 314 g kg^{-1} protein. The browse supplements from this study had varied effects on the utilization of dietary protein and this was probably influenced by different types and concentration of phenolics. Supplementation increased nitrogen retention about 9-fold. Tanninferous forages can be suitable protein sources, as long as the negative effects of tannins of increasing output of faecal N is less than their positive effect of reducing urinary-N loss. The positive responses obtained were attributed to the abilities of the browse supplements to overcome a nitrogen deficiency in teff straw by providing more ruminally degradable N and/or estimated escape N.

Most feeding trials on browse supplementation have been for short durations and focused mainly on feed intake, feed conversion and average daily gain. Information regarding their effects on the reproductive physiology of small ruminants is scarce and the available data is contradictory or inconclusive at best. Chapter 8 describes the long term effect of supplementation of *Leucaena pallida* and *Sesbania sesban* on the growth and scrotal circumference changes of Ethiopian Highland sheep and goats fed teff straw basal diet. Sheep had significantly higher ($P<0.05$) teff straw intake than goats (542 and 357 g, respectively). Substitution rate of teff straw (between the high and low level of supplementation) remained below 100 g and except for the goats supplemented with *S. sesban*. The correlation between scrotal circumference (SC) and body weight was high and significant in goats ($R^2=0.70$, $P<0.0001$) and lower in sheep ($R^2=0.43$, $P<0.01$). Increasing the amount of *L. pallida* supplement significantly increased LWG and scrotal circumference changes (SCC) in both sheep and goats. Sheep supplemented with *S. sesban* gained weight while goats on the same diet lost weight. Animals supplemented with *S. sesban* had significantly lower ($P<0.05$) SCC that the those supplemented with *L. pallida*. *Sesbania sesban* supplemented diets had

significantly higher (P>0.05) digestibilities of DM, OM, NDF and N than the other diets in goats, while the same was true for 400 g browse supplement treatments in sheep. Supplementation with browses increased faecal N output and N retention significantly (P<0.05) in both sheep and goats. N retention was significantly (P<0.05) higher in animals supplemented with 400 g browse than 200 g. The results from this study indicated type and level of supplement variations on the reproductive performance of sheep and goats as indexed by scrotal circumference changes.

Chapter 9 describes the effect of feeding sheep graded levels of browses on intake, digestibility and LWG. Teff straw was fed *ad libitum* (control diet), or supplemented with graded levels (15, 30, 45, 60% of DMI) of *Leucaena leucocephala*, *Leucaena pallida*, *Sesbania sesban* and *Chamaecytisus palmensis*. Significant (P<0.05) decrease in teff straw intake was observed, as the level of supplement increased. Total DM and OM intake increased (P<0.05) with increasing level *of L. leucocephala, C. palmensis* and *S. sesban*, but not in *L. pallida*. Substitution rates increased with increasing levels of supplementation. Live weight gain increased significantly (P<0.01) with increasing levels of browse supplementation. The animals fed the control diet lost weight (-24.4 g d^{-1}) while the supplemented ones gained weight in the range of 6.5 - 65.2 g d^{-1}. The maximum LWG (65.2 g d^{-1}) was observed in sheep fed a diet with 60% *L. pallida*. The optimum levels of browse supplementation (LWG per g supplement) were 45, 45, 30, 30% DM for *L. leucocephala, L. pallida, C. palmensis* and *S. sesban*, respectively.

The method developed to test palatability was suitable for evaluating palatability of large numbers of browses and other forages under stall feeding condition. Short palatability trials should be highly discouraged because animals show adaptation to feeds with time. If palatability carried out in order to predict long term intake, a period of 5 to 8 days should be allowed. Classification of browses based on either chemical composition, degradability or gas production characteristics leads to different cluster groups than when palatability indices are used. The *in vitro* N digestibility in combination with N, ADF or total phenolic levels in browses can predict digestibility of ruminally undegradable N. The *in vitro* method would considerably reduce the need for delicate surgery and the elaborate procedures involved in the mobile nylon bag technique. Tannin had beneficial attributes at low levels and detrimental effect at high levels. Some of the browse such as *Sesbania* species may have negative effect on reproduction. The optimum level of browse (*S. sesban, L. leucocephala, L. pallida, C. palmensis*) supplementation was 30 to 45% of the ration dry.

The work described in this thesis, aimed at developing indices that could be used to predict nutritive value of browses as supplements to poor quality roughage basal diets. The method developed to test palatability may be used in practice as a tool to segregate a large number of browse species into similar groups, whose representative members of each group can be studied in depth. Long term studies of the superior browse species are necessary as some of the species' negative effects are only observed in long term feeding trials. Classification of browses using palatability indices has advantages over use of degradation, gas production or chemical composition characteristics because some of the inherent animal and plant factors are taken into account. The digestibility of rumen undegradable N can be estimated by the pepsin/pancreatin *in vitro* method. Further development of standard methods of quantifying and assessment of biological effects of tannins and other anti-nutritional factors needs attention as the current methods are inadequate.

Samenvatting

In tropische en subtropische gebieden heeft de biomassa van natuurlijke graslanden en bijprodukten van granen, met name stro, vaak een laag eiwitgehalte en laat daarom geen hoge dierproduktie toe. Kwalitatief slecht voer en het seizoensgebonden karakter van de voedervoorziening zijn dan ook belangrijke oorzaken van de lage productiviteit van herkauwers. Het is bekend, dat wanneer rantsoenen bestaande uit gras en celwandrijke bijprodukten van graan met minder dan 7 % eiwit worden aangevuld met leguminosen, de droge stofopname en dierproductie verbeteren.

"Browses" (loof, ofwel scheuten en spruiten van zachte twijgen van houtachtige planten met bladeren en vruchten, die door het vee worden gegeten), worden momenteel, speciaal op kleine bedrijven, nog onvoldoende gebruikt in de diervoeding, mede omdat de juiste manier om ze te benutten nog onvoldoende begrepen wordt. "Browses" zijn van meer belang dan alleen als voer. In veel situaties zijn ze een onderdeel van complexe interacties tussen bodem, planten en dieren. Ze dragen bij tot het stabiliseren van het bodem-plant-dier ecosysteem. De bladeren van sommigen worden door mensen gebruikt als groente, terwijl wortels, schors, stengel en bladeren van anderen worden gebruikt voor medicinale doeleinden.

In de voeding van herkauwers functioneren "browses" als bron van (pens) afbreekbaar eiwit en/of bestendig eiwit, verteerbare energie en mineralen, zowel als aanvulling in rantsoenen of ook als enig voer. Van vele "browses" is bekend dat ze bruikbaar zijn als veevoer. Hoewel niet alle "browses" leguminosen zijn, wordt van meer dan 200 soorten bomen en struiken behorende tot de leguminosen het gebruik als veevoeder gerapporteerd, de meeste daarvan afkomstig uit tropen of subtropen. De meest gebruikte soorten behoren tot de geslachten *Acacia, Albizia, Calliandra, Desmanthus, Desmodium, Gliricidia, Leucaena, Proposis* en *Sesbania*. Ondanks de grote variatie hebben onderzoek en ontwikkelingswerk zich vooral geconcentreerd op een beperkte selectie uit de beschikbare soorten, met daarbij een prominente plaats voor *Leucaena leucocephala* en *Gliricidia sepium* in Azie en Afrika en voor *Erythrina poeppigiana* in Latijns Amerika. Dit is minder gelukkig omdat deze beperkte keus voorbij gaat aan vele andere waardevolle soorten zoals bijv. *Acacia*.

In veevoedingskundig opzicht vertonen "browses" veel variatie, zowel met betrekking tot de chemische samenstelling als wat betreft de effecten op de pensflora en op het dier. Deze verschillen in samenstelling kunnen worden toegeschreven aan verschillen in ouderdom, deel van de plant, oogstregime, seizoen, lokatie, concentratie aan anti-nutritionele stoffen (secundaire componenten) en de vorm (vers of gedroogd) en wijze van voeren. Deze factoren bepalen de chemische samenstelling, de smakelijkheid en opname, de afbreekbaarheid en afbraaksnelheid, de verteerbaarheid en de benutting van voedingsstoffen door herkauwers die verder overwegend kwalitatief laagwaardig voer krijgen.

Er is geen eenvoudige en eenduidige parameter die de kwaliteit van "browses" voorspelt, omdat de chemische samenstelling alleen de voederwaarde onvoldoende voorspelt. Het belangrijkste doel van het hier behandelde onderzoek was daarom het ontwikkelen van parameters die gebruikt kunnen worden om de voederwaarde van "browses" als

eiwitaanvulling in een kwalitatief arm basisrantsoen, te voorspellen. Bij het ontwikkelen van deze parameters werd aandacht besteed aan de methodiek om grote aantallen "browses" te screenen in voerproeven, aan de keuze van de te gebruiken diersoort en aan het aandeel van "browses" in het rantsoen.

Hoofdstuk 1 geeft een overzicht van het gebruik en de beperkingen voor een efficiënte benutting van "browses". De voederwaarde van voer hangt af van de opname en van de mate waarin de opgenomen droge stof het dier voorziet van energie, eiwitten, mineralen en vitaminen. Veel hangt daarom af van de werkelijke dagelijkse voeropname. Bij "browses" is de opname naar verwachting relatief laag, deels vanwege de beperkte beschikbaarheid, maar ook omdat ze zelden alleen gegeten worden. De smakelijkheid is bij "browses" even belangrijk als de verteerbaarheid omdat velen anti-nutritionele componenten bevatten waarvan bekend is dat ze de smakelijkheid negatief beïnvloeden. De smakelijkheid van "browses" wordt toegeschreven aan zowel fysische eigenschappen (behaardheid en dichtheid) als aan stoffen die smaak en eetlust beïnvloeden (vluchtige oliën, oplosbare koolhydraten, anti-nutritionele factoren).

Er is een aantal proeven uitgevoerd om de smakelijkheid van "browses" te onderzoeken. De gebruikelijke methoden om de voorkeur voor een bepaald ruwvoer te meten (slokdarmfistels, onderzoek van de pensinhoud of van faeces) zijn echter niet geschikt om een hele reeks "browses" te screenen, omdat ze arbeidsintensief, duur en gecompliceerd zijn. In hoofdstuk 2 wordt een methode beschreven die gebaseerd is op het volgen en meten van eetgedrag en opname in voederproeven met op stal gehuisveste dieren met 40 soorten "browses". De keuze van de proefduur was daarbij belangrijk. Het vaststellen van de smakelijkheid gedurende 5-8 dagen gaf de beste voorspelling van de opname en een stabiele volgorde van de voorkeur bij schapen. De 40 "browses" werden onderverdeeld in 4 groepen gebaseerd op een ontwikkelde index voor smakelijkheid.

In hoofdstuk 3 zijn representatieve soorten geselecteerd van elk van de 4 hiervoor op smakelijkheid gebaseerde groepen om de methodiek voor het vaststellen van de smakelijkheid te valideren en om het effect van voorbehandeling (voorgedroogd of als hooi) en diersoort (schapen of geiten) te onderzoeken. Geiten hadden een sterkere voorkeur voor "browses" dan schapen. Voordrogen of hooien had geen invloed op de index. De gemeten index bleek ook samen te hangen met de vooraf gevormde groepen. De resultaten van dit onderzoek geven aan dat de ontwikkelde methode geschikt is voor het vaststellen van de smakelijkheid bij "browses".

Een groot aantal "browses" worden landbouwkundig geëvalueerd, in het bijzonder met betrekking tot oogststadium en voederwaarde. In aanvulling op de reactie van het dier werden van deze browses ook onderzocht de fermentatiekarakteristieken in de pens, alsmede, met mobiele nylon zakjes (MNB), de verteerbaarheid in de dunne darm. Hoofdstuk 4 beschrijft het verband tussen de smakelijkheid en chemische samensteiling, gasproductie en pensfermenteerbaarheid, dit om na te gaan welke van deze methoden de smakelijkheid en de opname het beste kan voorspellen. Smakelijkheid en droge stofopname (DMI) waren negatief gecorreleerd met het gehalte aan neutral detergent fiber (NDF), acid detergent fiber (ADF) en lignine en positief met de aan NDF gebonden stikstof (NDFN). Het gehalte aan fenolen was sterker gecorreleerd met afbreekbaarheid van de droge stof en de gasproductie

dan met de smakelijkheid en de droge stofopname. Er wordt geconcludeerd dat chemische componenten als N, NDF, NDFN, ADF en lignine essentieel zijn om de voederwaarde van "browses" te beschrijven. Groepen gebaseerd op vergelijkbare smakelijkheid verschilden van die gebaseerd op verschil in chemische samenstelling, gasproductie of afbreekbaarheidskarakteristieken. Het is daarom nodig om te proberen ook de smakelijkheid te bepalen van "browses" die op voederwaarde gescreend worden.

In rantsoenen die alleen uit ruwvoer bestaan is de eiwitwaarde van elke component belangrijk om het effect van supplementatie te kunnen bepalen. De nieuwe systemen van eiwitwaardering verdelen voereiwit in een deel dat in de pens wordt afgebroken en een bestendig deel dat niet afbreekt. In hoofdstuk 5 zijn de mobiele nylon zakjes (MNB) techniek en de *in vitro* pepsine/pancreatine methode (IV) gebruikt om de verteerbaarheid van het bestendige voereiwit te bepalen. "Browses" met een hoog gehalte aan tanninen zoals *Acacia hockii, Acacia horrida, Acacia melanoxylon, Acacia persiciflora, Acacia salicina, Acacia saligna* en *Flemingia macrophylla* bevatten een hoog gehalte aan bestendig eiwit, met een lage verteerbaarheid van het bestendige residu (ND). *Acacia sieberiana, Chamaecytisus palmensis, Erythrina* spp, *Gliricidia sepium, Samaena saman* en *Enterolobium cyclocarpum* hadden een hoog gehalte bestendig eiwit, waarvan een groot deel verteerbaar was. De verteerbaarheid van het bestendige eiwit bepaald met de MNB methodiek was significant lager dan bij de IV methode. Via lineaire regressie van MNB met IV werd 0.89 van de variantie verklaard, hetgeen een sterke relatie aangeeft tussen deze 2 methoden. Het intercept verschilde significant van 0, terwijl de richtingscoëfficiënt niet afweek van 1. Dit betekent dat de bepaling van ND via IV de verteerbaarheid overschat in vergelijking met MNB. Multipele regressieanalyse suggereert dat dit verschil gecorrigeerd kan worden door de via IV bepaalde verteerbaarheid te corrigeren voor de hoeveelheid N, ADF of TP in "browses". De IV methode is daarom geschikt om de verteerbaarheid van bestendig eiwit te bepalen. Het gebruik ervan zal de noodzaak van gecompliceerde operatieve ingrepen zoals bij de mobiele nylon zakjes methode en de daarbij horende arbeidsintensieve procedures, aanzienlijk kunnen reduceren.

Aan tanninen worden soms gunstige effecten toegeschreven in de voeding van herkauwers, dankzij eigenschappen als het onderdrukken van trommelzucht, het beperken van de negatieve effecten van maag- en darmwormen op de productie en het tegengaan van de excessieve afbraak van hoogwaardig eiwit in de pens met als gevolg dat er meer hoogwaardig eiwit in de dunne darm komt. In hoofdstuk 6 en 7 wordt de reactie beschreven van schapen gevoerd op een controle rantsoen van stro van teff (Eragrostis tef), op bijvoedering met blad van *Dolichos lablab, Chamaecytisus palmensis, Leucaena leucocephala, Sesbania goetzei*, en 6 lijnen van *Sesbania sesban* (S1190, S1198, S2024, S10865, S15019 en S15036) met verschillend tanninengehalte. Bijvoedering verhoogde de vrijwillige voeropname (DMI) en de dagelijkse groei (LWG) significant. De dieren op het controle rantsoen verloren gewicht (-1.9 g $kg^{-0.75}$), terwijl de bijgevoederde dieren groeiden (2.9- 4.4 g $kg^{-0.75}$). Bijvoedering met *Leucaena* verhoogde de LWG ($P<0.05$) meer dan die met Lablab, S1190 en goetzei. Met een toenemend tanninengehalte (binnen *Sesbania* lijnen) was er eerst een stijging in LWG (S1190<S1198<S10865<S15019), gevolgd door een daling (S2024>goetzei>S15036). Toenemende tanninengehalten gingen ook samen met een stijging

van de hoeveelheid bestendig eiwit en faecaal eiwit, en een daling van de hoeveelheid urine N. Bijvoedering verhoogde de hoeveelheid faecaal N significant, evenals de N retentie. De schijnbare verteerbaarheid van N was positief gecorreleerd ($P<0.001$) met de supplementatie met droge stof, de afbreekbaarheid van eiwit na 24 uur ($r = 0.93$ en $r = 0.85$ resp.) en het gehalte aan ruw eiwit ($r = 0.87$), en negatief met ADF en NDF ($r = -0.87$ en $r = -0.87$ resp.). De geschatte hoeveelheid in de pens afbreekbaar eiwit van de supplementen varieerde van 482 tot 744 g per kg, terwijl de hoeveelheid dunne darm verteerbaar eiwit varieerde van 140 tot 314 g per kg. De "browse" supplementen in deze studie hadden een verschillend effect op de benutting van het rantsoeneiwit. Dit effect werd waarschijnlijk beïnvloed door verschil in type en gehalte aan fenolen. Bijvoedering verhoogde de N retentie ongeveer negenvoudig. Tannine houdende ruwvoeders kunnen geschikte eiwitbronnen zijn zo lang het negatieve effect als gevolg van een hogere uitscheiding van de hoeveelheid faecaal N kleiner is dan het positieve effect via de daling van de uitscheiding van urine N. De positieve effecten van "browses" als supplement moeten worden toegeschreven aan de eigenschap om het eiwittekort van teff stro op te heffen via een hoger aanbod van afbreekbaar eiwit en/of bestendig eiwit.

De meeste uit de literatuur bekende proeven met bijvoedering van "browses" zijn van korte duur geweest of concentreerden zich op de voeropname, de voederconversie en de gemiddelde dagelijkse groei. Informatie met betrekking tot het effect op de fysiologie van de reproductie van kleine herkauwers is schaars en de beschikbare resultaten zijn op zijn best niet eenduidig of zelfs tegenstrijdig. In hoofdstuk 8 wordt het lange termijn effect onderzocht van bijvoedering met 2 niveaus *Leucaena pallida* en *Sesbania sesban* op de groei en omvang van het scrotum van mannelijke schapen van het ras Ethiopian Highland en van mannelijke geiten die gevoerd werden op een basisrantsoen van teff stro. De gemiddelde stro-opname van schapen was significant ($P<0.05$) hoger dan van geiten (resp. 542 en 357 g per dier dag). De verdringing van teff stro bleef beneden 100 g (tussen het hoge en lage niveau van bijvoedering), behalve voor geiten die werden bijgevoerd met *S. sesban*. De correlatie tussen de omvang van het scrotum (SC) en het lichaamsgewicht was hoog en significant bij bokken ($R^2 = 0.70$, $P<0.0001$) en lager bij rammen ($R^2 = 0.43$, $P<0.01$). Een grotere hoeveelheid *L. pallida* verhoogde de LWG en vergrootte de verandering in scrotum omvang (SCC) significant, zowel bij rammen als bij bokken. Schapen die werden bijgevoerd met *S. sesban* groeiden, terwijl geiten lichter werden op hetzelfde rantsoen. De dieren die werden bijgevoerd met *S. sesban* hadden een significant geringere toename van SCC ($P<0.05$) dan die bijgevoerd met *L. pallida*. De verteerbaarheid van droge stof, organische stof, NDF en N van rantsoenen met *S. sesban* was bij geiten significant hoger dan met *L. pallida* Hetzelfde was het geval bij schapen bijgevoerd op een niveau van 400 g "browse". Bijvoedering met "browses" verhoogde de uitscheiding van faecaal N en de N retentie significant ($P <0.05$), zowel bij schapen als geiten. De N retentie was significant hoger ($P< 0.005$) bij bijvoedering met 400 g "browse" dan bij 200 g. De resultaten van dit onderzoek geven aan dat aard en niveau van de bijvoedering de fertiliteit van rammen en bokken beïnvloeden bij meting op basis van de scrotum omvang.

Hoofdstuk 9 beschrijft het effect van voeren van verschillende hoeveelheden van een aantal "browses" op opname, verteerbaarheid en LWG. Als controle werd ad lib stro van teff

gevoerd. Dit werd gesupplementeerd met "browses" (15, 30, 45 en 60 % van de DMI) van *Leucaena leucocephala*, *Leucaena pallida*, *Sesbania sesban* en *Chamaecytisus palmensis*. De opname van teff stro ging significant ($P < 0.05$) omlaag als het niveau van bijvoedering steeg. De totale opname aan droge stof en organische stof steeg ($P<0.05$) naarmate meer "browse" van *L. leucocephala*, *S. sesban* en *C. palmensis* werd bijgevoerd, maar niet bij *L. pallida*. De verdringing werd groter bij een hoger niveau van bijvoedering. De groei steeg significant ($P < 0.05$) met het niveau van bijvoedering. De dieren op het controle rantsoen verloren gewicht (-24.4 g per dag), terwijl de bijgevoerde dieren 6.5-65.2 g per dier per dag groeiden. De maximum LWG (65.2 g per dag) werd waargenomen bij schapen op een rantsoen met 60 % *L. pallida*. Het optimale niveau van bijvoedering met "browses" (LWG per g supplement) was 45, 45, 30 en 30 % voor resp. *L. leucocephala, L. pallida, C. palmensis* en *S. sesban*.

Afsluitend kan uit dit onderzoek een aantal conclusies worden getrokken:

De in deze studie ontwikkelde methode voor de beoordeling van de smakelijkheid is geschikt voor het evalueren van grote aantallen "browses" en andere ruwvoeders bij voedering op stal. Kortdurende proeven om de smakelijkheid te bepalen moeten sterk worden ontraden omdat de dieren met de tijd wennen aan voeders. Als de smakelijkheid wordt bepaald om de opname op langere termijn te voorspellen is een proefduur van 5-8 dagen gewenst. Classificatie van "browses" op basis van chemische samenstelling, afbreekbaarheid in de pens of gasproductie leidt tot een verschil in groepering in vergelijking met classificatie op basis van de smakelijkheid. Gebruik van de *in vitro* N verteerbaarheid in combinatie met een correctie voor N, ADF of TP, kan de verteerbaarheid van in de pens bestendig N voorspellen. De *in vitro* methode beperkt de noodzaak van gecompliceerde operatieve ingrepen, zoals die nodig zijn bij de mobiele nylon zakjes techniek. Tanninen hebben positieve effecten bij lage gehalten en schadelijke gevolgen bij een hoog gehalte. Sommige "browses", zoals *Sesbania sesban*, hebben een negatief effect op de reproductie. Het optimale niveau van supplementatie varieert bij rantsoenen gebaseerd op teff stro op droge stof basis van 30 tot 45 %.

Het in dit proefschrift beschreven onderzoek had tot doel het ontwikkelen van parameters om de voederwaarde te voorspellen van "browses" die gebruikt worden als supplement in rantsoenen met laagwaardig ruwvoer. De ontwikkelde methode voor de bepaling van de smakelijkheid kan in de praktijk worden gebruikt om grote aantallen "browses" onder te verdelen in gelijksoortige groepen, waarvan vervolgens representatieve soorten meer gedetailleerd onderzocht kunnen worden. Lange termijn studies van "browse" soorten zijn vaak noodzakelijk, omdat de negatieve effecten van sommige soorten alleen dan zichtbaar worden. Een classificatie van "browses" op basis van smakelijkheid heeft voordelen ten opzichte van de bepaling van de bestendigheid, gasproductie of chemische samenstelling, omdat sommige van de aan plant en dier inherente factoren dan ook worden meegenomen. De verteerbaarheid van bestendig N kan worden geschat met de pepsine/pancreatine *in vitro* methode. Verdere ontwikkeling van standaardmethoden om biologische en andere effecten van tanninen en andere anti-nutritionele factoren te meten en in te schatten vragen aandacht, omdat de huidige methoden niet adequaat zijn.

CURRICULUM VITAE

Robert Josiah Kaitho was born on April 24, 1963 in Machakos, Kenya. From 1985 to 1988 he studied agriculture at University of Nairobi, where he obtained a BSc degree in agriculture. After graduation he was employed by Kenya Agricultural Research Institute (KARI) as an Assistant Research Officer and attached to the National Animal Husbandry Research Centre, Naivasha. In September 1990 he started MSc animal science programme at the Wageningen Agricultural University, The Netherlands. On his return to Kenya in 1992, he was promoted to a Research Officer in the dairy research programme. In 1992, he attended an international training course entitled "Fodder Tree Legumes-Multipurpose Species for Agriculture" conducted at the University of Queensland, Australia. In October 1994, the International Livestock Research Institute (ILRI) formerly International Livestock Centre for Africa (ILCA) graded him a graduate associate position where he carried out PhD research in a sandwich arrangement with the Wageningen Institute of Animal Science, Animal Nutrition Group.