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# Nutritional, antinutritional and phytomedicinal attributes of tree fodders and their impact on livestock health and productivity: A comprehensive review

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**Abstract**

Seasonal fodder scarcity, land degradation, and climate-induced variability increasingly constrain sustainable livestock production systems, particularly in tropical and semi-arid regions. Tree fodders, comprising leaves, pods, shoots, and twigs of woody perennials, offer a resilient alternative by providing year-round biomass, superior nutritional quality, and bioactive phytochemicals. This review synthesises current knowledge on the nutritional composition, phytomedicinal properties, and anti-nutritional factors (ANFs) of major tree fodder species used globally, with special emphasis on India. Tree fodders, especially leguminous species such as *Leucaena leucocephala*, *Moringa oleifera*, *Gliricidia sepium*, and *Sesbania grandiflora* are rich in crude protein (15-30% DM), minerals, vitamins, and metabolizable energy, making them effective supplements to low-quality roughages during lean seasons. Beyond nutrition, tree fodders contain phytochemicals-including tannins, saponins, flavonoids, and alkaloids-that exhibit antimicrobial, anthelmintic, antioxidant, anti-inflammatory, and immunomodulatory effects, positioning them as functional feeds within the food-feed-medicine continuum. However, excessive concentrations of ANFs such as condensed tannins, mimosine, oxalates, and phytates can impair intake, nutrient digestibility, mineral bioavailability, and animal health. The review highlights the dose-dependent duality of these compounds and discusses mitigation strategies, including processing, dietary dilution, supplementation, and species-specific feeding management. Key research gaps related to standardised ANF assessment, safe inclusion thresholds, long-term animal health impacts, and climate interactions are identified. Overall, strategic utilisation of tree fodders (15-40% of dietary dry matter) can enhance livestock productivity, health, and system resilience, supporting sustainable and climate-adaptive livestock production.

## 1. Introduction

Seasonal shortages of fodder, destruction of grazing lands, and the rivalry of food and feed production of arable lands have resulted in livestock production systems around the world that are confronted with unprecedented challenges in satisfying the nutritional needs of the livestock (Devendra, 2012). Traditional fodder sources are becoming insufficient, especially in dry seasons, when herbaceous vegetation becomes of low quality and scarce in quantity. Climate change has worsened this situation because it has increased the intensity and frequency of droughts and is a risk to the sustainability of livestock livelihoods (Thornton *et al*., 2009). Tree fodders include leaves, pods, twigs, and shoots of plants of multiple woody types; they were the most important feed sources, particularly in arid and semi-arid zones with their extensive root systems that provide biomass throughout the year (Singh *et al*., 2017). In addition to having been described as emergency feeds during periods of is scarcity, tree fodders are also being noted to have high nutritional value as well as bioactive phytochemical compounds that have the potential to improve the health and productivity of the animals (Patra, 2010).

These multifunctional trees are compatible with the agroforestry system and, in addition to the fodder, they can also supply fuel, timber, and ecological functions like soil conservation and sequestration of carbon (Kumar and Singh, 2005). Tree fodders have been of particular concern because of the food-feed-medicine continuum, most have compound that act as nutrients, growth regulators, and therapeutics (Salem and Smith, 2008). Phytochemicals like tannins, saponins, flavonoids, and alkaloids have a variety of biological properties, including antimicrobial, anthelmintic, and antioxidant properties that can diminish the application of synthetic veterinary drugs and facilitate the production of organic livestock (Athanasiadou *et al*., 2007). Yet the same compounds can be ANFs when they occur at high concentrations, causing interference with the digestion, absorption, and utilisation of nutrients (Makkar, 2003).

## 2. Tree fodders in livestock feed systems

### 2.1 Definition and importance

Tree fodders are the edible parts of woody perennial plants, such as leaves, young shoots, flowers, fruits and pods, that are either browsed

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by livestock or utilised as harvested feed supplements (Pandey and Roy, 2011). Compared to herbaceous fodders, tree fodders possess several unique benefits. Their deep root systems tap moisture and nutrients in deeper levels of soil, thus producing biomass in dry seasons (Sanchez, 2002). The ecological importance of tree fodders includes improved soil fertility through nitrogen fixation by leguminous species, erosion control, microclimate improvement, and biodiversity conservation in agroforestry systems (Nair, 2012). Socio-economically, tree fodder decreases dependence on purchased feeds and diminishes production expenses (Franzel *et al*., 2014).

### 2.2 Classification of tree fodders

Depending upon botanical, phenological, and nutritional traits, tree fodder can be classified into two main divisions: leguminous and non-leguminous species. The Fabaceae family consists of leguminous tree fodders, which fix nitrogen through symbiotic interactions with rhizobia, yielding crude protein values of 15-30% dry matter (DM) compared to 8-15% in non-leguminous species (Kaitho*et al*., 1998). Leguminous tree fodders include *Leucaena leucocephala, Sesbania grandiflora,Acacia leucophloea, Gliricidia sepium,* and *Moringa oleifera*. Non-leguminous tree fodders include species from Moraceae (*Ficus* spp.), Euphorbiaceae (*Ricinus* spp.), and Ulmaceae (*Ulmus* spp.). Tree fodders are also classified phenologically as either evergreen or deciduous.

### 2.3 Important tree fodder species utilised in India and the World

*L. leucocephala* is considered the most popular fodder tree in the world because of its high biomass production, good quality proteins (20-25% CP), and palatability (Brewbaker, 1986). *G. sepium* is used widely in Central and South America and Asia due to its high protein content and success in silvopastoral systems (Stewart *et al*., 2019). In India, Ficus species (banyan, peepal) are regarded as sacred traditional fodder trees, while *M. oleifera* has become internationally recognised due to its outstanding nutritional content, with crude protein reaching 25-30%, richness in vitamins and minerals, and a variety of bioactive compounds (Nouman *et al*., 2014). Other significant species in the Indian subcontinent include *Azadirachta indica* (neem), *Hardwickia binata*, *Albizia* spp., and several *Acacia* spp. (Singh and Todaria, 2012). Recent studies suggested that invasive alien tree species *Senna spectabilis* found across southern India, as potential fodder during scarcity periods (Bargavi *et al.,* 2025).

## 3. Nutritional composition of tree fodders

### 3.1 Macronutrient profile

The protein content of tree fodders is very variable, ranging from 12-30% depending on species, plant part, and growth stage (Devendra, 1992). Leguminous tree fodders have high levels of protein compared to grasses and non-leguminous fodders. The leaves of *M. oleifera* are outstanding with 25-30% crude protein (CP), and *L. leucocephala* has 20-25% CP (Makkar and Becker, 1996). Real protein digestibility of tree fodder ranges between 40-80%, significantly less than standard protein supplements such as soybean meal (85-90%), largely because of tannin-protein complexes (Reed, 1995). However, moderate concentrations of tannin (2-4% DM) may have positive effects in decreasing protein destruction in the rumen and increasing post-ruminal amino acid supply, a phenomenon known as protein protection (Barry and McNabb, 1999).

Tree fodders contain structural carbohydrates-neutral detergent fibre (NDF) and acid detergent fibre (ADF) as the largest energy fraction. NDF is usually 30-60% DM, whereas ADF is 20-45% DM. The metabolizable energy (ME) range is 6-10 MJ/kg DM. The macronutrient profile of tree fodder, especially the leguminous ones, make themsuitable supplements to poor-quality crop residues and grasses during dry seasons (Table 1).

**Table 1: Nutritional composition of major tree fodder species**

| Tree fodder species | CP (%) and CF (%) | DMD (%) | ME (MJ/kg) | Ca (%) and P (%) | References |
|---|---|---|---|---|---|
| *L. leucocephala* | 20-30 and 15-20 | 55-65 | 8.5-9.5 | 1.8-2.0 and 0.18-0.25 | Shelton and Brewbaker, 1994; D'Mello, 1992 |
| *G. sepium* | 18-28 and 18-25 | 50-60 | 8.0-9.0 | 1.2-1.5 and 0.20-0.25 | Roshetko and Gutteridge, 1990 |
| *S. grandiflora* | 22-32 and 12-18 | 60-70 | 9.0-10.0 | 1.0-1.3 and 0.25-0.30 | Evans and Rotar, 1987; Gutteridge and Shelton, 1994 |
| *M. oleifera* | 25-30 and 10-15 | 65-75 | 9.5-11.0 | 1.8-2.2 and 0.30-0.40 | Makkar and Becker, 1997; Fuglie, 2001 |
| *Morus alba* | 15-28 and 12-18 | 70-80 | 10.0-11.5 | 1.5-2.0 and 0.25-0.35 | Sánchez, 2002; Singhal *et al*., 2010 |
| *Ficus benghalensis* | 12-18 and 20-28 | 45-55 | 7.5-8.5 | 1.2-1.6 and 0.15-0.20 | Singh and Prabhakar, 1985; Chandrasekar *et al*., 1990 |
| *A. indica* | 14-20 and 18-25 | 48-58 | 7.8-8.8 | 1.0-1.4 and 0.18-0.23 | Koul *et al*., 1990; Singh and Sastry, 1981 |
| *A. nilotica* | 12-18 and 22-30 | 40-50 | 7.0-8.0 | 1.5-2.0 and 0.15-0.22 | Dube *et al*., 2000; Singh *et al*., 2009 |
| *Albizia lebbeck* | 16-22 and 20-28 | 45-55 | 7.5-8.5 | 1.3-1.7 and 0.20-0.28 | Duke, 1983; Krisnachinda and Limpinuntana, 1992 |
| *H. binata* | 10-15 and 25-35 | 35-45 | 6.5-7.5 | 1.8-2.2 and 0.12-0.18 | Pathak and Kumar, 1982; Singh and Mishra, 1988 |
| *Prosopis juliflora* | 14-20 and 20-28 | 45-55 | 7.5-8.5 | 1.2-1.8 and 0.18-0.24 | Felker and Bandurski, 1979; Simpson, 1977 |
| *Erythrina indica* | 18-24 and 16-22 | 52-62 | 8.2-9.2 | 1.4-1.8 and 0.22-0.28 | Little and Skolmen, 1989; Westley and Powell, 1993 |

CP = Crude Protein; CF = Crude Fiber; DMD = Dry Matter Digestibility; ME = Metabolizable Energy; Ca = Calcium; P = Phosphorus

### 3.2 Micronutrients and vitamins

Tree fodders are mostly good in mineral content, especially calcium, phosphorus, magnesium, and trace elements such as iron, zinc, copper, and manganese (Tolera *et al*., 1997). Leguminous tree fodders usually contain higher levels of calcium in their DM (1-3%) compared to grasses, which is advantageous to lactating animals. The Ca:P ratio in tree fodders (2:1 to 5:1) supports optimal mineral utilisation (Bakshi and Wadhwa, 2004). In addition to containing fat-soluble vitamins (A, D, E, K) and water-soluble B-vitamins, tree fodder leaves are high sources of beta-carotene, with *M. oleifera* having up to 6.8 mg/100 g fresh weight (Fuglie, 2001).

### 3.3 Seasonal, phenological, and processing effects

The crude protein is greatest (25-35%) during the wet season and early vegetation growth, while it decreases as plants mature and fibre and lignin contents increase (Tolera *et al*., 1997). Food processing has a great effect on nutrient retention and palatability. Sun-drying may reduce moisture to 10-15% but may lead to 15-30% loss of crude protein and 40-60% of carotenes (Singh and Singh, 2003). Ensiling tree fodder combined with molasses or grains reduces tannin activity by 20-40% and successfully detoxifies cyanogenic glycosides (Melesse *et al*., 2017).

### 3.4 Nutritional advantages compared to traditional fodders

Comparative studies have consistently shown the nutritional benefit of tree fodders over traditional fodders at critical times. A study comparing *L. leucocephala* foliage and dry-season grass hay found that *L. leucocephala* has 23% CP while dry grass hay has 6% CP, with *L. leucocephala* offering 8.5 MJ/kg ME versus 6.8 MJ/kg for hay (Devendra, 1992). When tree fodder takes up 20-40% of the diet, it can equalise low-protein crop residues, enhancing overall diet quality and animal output (Singh *et al*., 2017). *S. spectabilis* feed pellets as supplementary livestock feed ingredients show 15.75-16.62% CP and Total digestible nutrients (TDN) ranges between 90.08-92.64%.

## 4. Phytochemical constituents and phytomedicinal properties

### 4.1 Major phytochemical groups in tree fodders

The secondary metabolites in tree fodder are highly varied, evolved as plant strategies to cope with herbivores, pathogens, and environmental stress (Patra and Saxena, 2009). Significant phytochemical categories include tannins, saponins, flavonoids, alkaloids, essential oils, and other phenolic compounds (Figure 1).

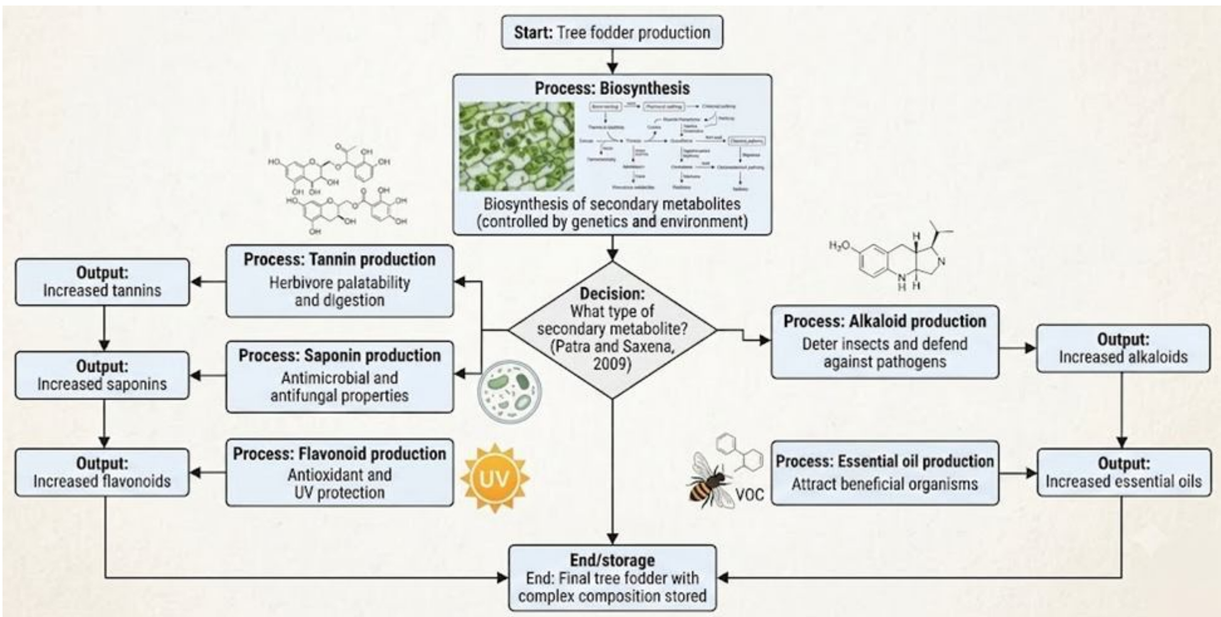


**Figure 1: Flowchart of secondary metabolites in tree fodder.**

#### 4.1.1 Tannins

Tannins fall into two categories: hydrolysable tannins (HT) and condensed tannins (CT) or proanthocyanidins. Tree fodder tannin concentrations range below 15% DM with significant species variation (Mueller-Harvey, 2006). Leguminous tree fodders are usually rich in CT: *Acacia*spp., 5-12% CT, *L. leucocephala* 2-7%, and *Calliandra calothyrsus* 8-15% DM. Tannins form complexes with proteins that are resistant at ruminal pH and dissociate at acidic abomasal pH, which might increase the absorption of amino acids (Barry and McNabb, 1999).

#### 4.1.2 Saponins

Saponins are surfactants comprising glycosidic compounds found in most leguminous tree fodders. Concentrations of 0.5-5% DM are common, with notable sources including *Sesbania* spp. and *Acacia* spp. (Cheeke, 2000). Saponins have been shown to alter rumen fermentation by influencing protozoa populations and methane production (Patra and Saxena, 2011).

#### 4.1.3 Flavonoids

Flavonoids, including flavonols, flavones, and isoflavones, are widespread throughout tree fodders at 0.5-3% DM. These substances display strong antioxidant properties, involving free radical scavenging and protection against oxidative stress (Cushnie and Lamb, 2005). *M. oleifera* contains especially notable flavonoids such as quercetin and kaempferol (Nouman *et al*., 2014).

#### 4.1.4 Alkaloids

Alkaloids are biologically active nitrogen-containing compounds. Mimosine, found in *L. leucocephala* at 2-5% DM in young leaves, is the most studied alkaloid in tree fodder (D'Mello and Acamovic, 1989). Essential oils and phenolic acids also contribute antimicrobial and antioxidant activity, with concentrations changing seasonally (Patra, 2010).

### 4.2 Phytomedicinal properties relevant to livestock

#### 4.2.1 Antimicrobial activity

Phytochemicals of many tree fodder species show inhibitory actions to pathogenic bacteria, fungi, and protozoa (Cowan, 1999). Tannins disrupt microbial cell membranes and prevent bacterial enzymes, while saponins form complexes with membrane sterols, causing cell lysis (Patra and Saxena, 2009). Extracts of *M. oleifera* have been found active against *Staphylococcus aureus, Escherichia coli,* and *Salmonella* spp. due to flavonoids and isothiocyanates (Mahajan *et al*., 2007).

**Table 2: Phytomedicinal properties of major tree fodder species**

| Tree fodder species | Major bioactive compounds | Medicinal properties | Traditional uses | References |
|---|---|---|---|---|
| *L. leucocephala* | Flavonoids, phenolics, mimosine | Anthelmintic, antimicrobial, anti-inflammatory | Parasitic control, wound healing | D'Mello, 1992; Shelton and Brewbaker, 1994 |
| *G. sepium* | Coumarin, tannins, flavonoids | Antiparasitic, insecticidal, antioxidant | Ectoparasite control, skin diseases | Roshetko and Gutteridge, 1990 |
| *S. grandiflora* | Flavonoids, saponins, alkaloids | Antidiabetic, hepatoprotective, antimicrobial | Digestive disorders, liver protection | Evans and Rotar, 1987; Gutteridge and Shelton, 1994 |
| *M. oleifera* | Glucosinolates, isothiocyanates, quercetin | Antioxidant, anti-inflammatory, immunomodulatory | Nutritional supplement, immunity booster | Makkar and Becker, 1997; Anwar *et al*., 2007 |
| *Morus alba* | Anthocyanins, flavonoids, alkaloids | Antidiabetic, antihyperlipidemic, cardioprotective | Metabolic disorders, cardiovascular health | Sánchez, 2002; Singhal *et al*., 2010 |
| *Ficus benghalensis* | Tannins, flavonoids, steroids | Anti-inflammatory, wound healing, antimicrobial | Diarrhea, dysentery, skin infections | Chandrasekar *et al*., 1990; Singh and Prabhakar, 1985 |
| *A. indica* | Azadirachtin, nimbin, quercetin | Antiparasitic, antibacterial, immunomodulatory | Parasitic control, skin diseases, immunity | Koul *et al*., 1990; Singh and Sastry, 1981 |
| *Acacia nilotica* | Tannins, gallic acid, catechin | Astringent, antimicrobial, wound healing | Diarrhea, wounds, dental problems | Singh *et al*., 2009; Dube *et al*., 2000 |
| *A. lebbeck* | Saponins, tannins, flavonoids | Antihistaminic, anti-asthmatic, anti-inflammatory | Respiratory disorders, allergies | Duke, 1983; Krisnachinda and Limpinuntana, 1992 |
| *H. binata* | Tannins, phenolics, flavonoids | Antimicrobial, antioxidant, astringent | Digestive disorders, skin conditions | Singh and Mishra, 1988; Pathak and Kumar, 1982 |
| *P. juli flora* | Alkaloids, flavonoids, tannins | Antimicrobial, anti-inflammatory, antioxidant | Wound healing, digestive issues | Simpson, 1977; Felker and Bandurski, 1979 |
| *E. indica* | Alkaloids, flavonoids, isoflavones | Sedative, anti-inflammatory, antimicrobial | Nervous disorders, inflammation, infections | Westley and Powell, 1993; Little and Skolmen, 1989 |

#### 4.2.2 Anthelmintic properties

Gastrointestinal parasites constitute a significant limitation to livestock growth globally, and the problem of anthelmintic resistance continues to rise (Hoste *et al*., 2006). Condensed tannins in tree fodder have shown anthelmintic effects against nematodes through interference with parasite feeding, inhibition of larval development, and changes in adult worm movement and egg-bearing (Athanasiadou *et al*., 2007). Research with Acacia, Calliandra, and *L. leucocephala* demonstrated a decline in fecal egg counts and worm burdens in sheep and goats (Min and Hart, 2003).

#### 4.2.3 Antioxidant activity

Flavonoids, phenolic acids, and other polyphenols in tree fodders act as antioxidants, neutralising reactive oxygen species (ROS) and preventing oxidative damage (Scalbert and Williamson, 2000). Dietary antioxidants of forage can enhance the antioxidant defence system of the animal and improve cellular functions (Surai, 2014). *M. oleifera* has been found to possess especially high antioxidant ability both *in vitro* and *in vivo* (Makkar and Becker, 1996).

#### 4.2.4 Anti-inflammatory and immunomodulatory effects

Phytochemicals such as flavonoids, tannins, and triterpenes have anti-inflammatory effects through the regulation of inflammatory mediators like cytokines, prostaglandins, and nitric oxide (Pan *et al*., 2010). Saponins are immunoadjuvants that boost antibody responses to antigens and vaccines (Cheeke, 2000). Polysaccharides from Moringa and other species activate macrophages and cytokine production (Gupta *et al*., 2010).

### 4.3 Mechanisms of action in livestock systems

Phytochemicals have a major impact on rumen microbial ecology and fermentation patterns. Tannins selectively inhibit protein-degrading bacteria, altering fermentation towards greater propionate production and reduced ammonia formation (Patra and Saxena, 2011). Saponins can lower the level of protozoa, cutting methane emissions by 15-30% since protozoa host methanogenic archaea (Hess *et al.*, 2003). In moderate concentrations (2-4% DM), tannins also promote protein protection by reducing ruminal protein degradation, as discussed in Section 3.1 (Barry and McNabb, 1999) (Figure 2).

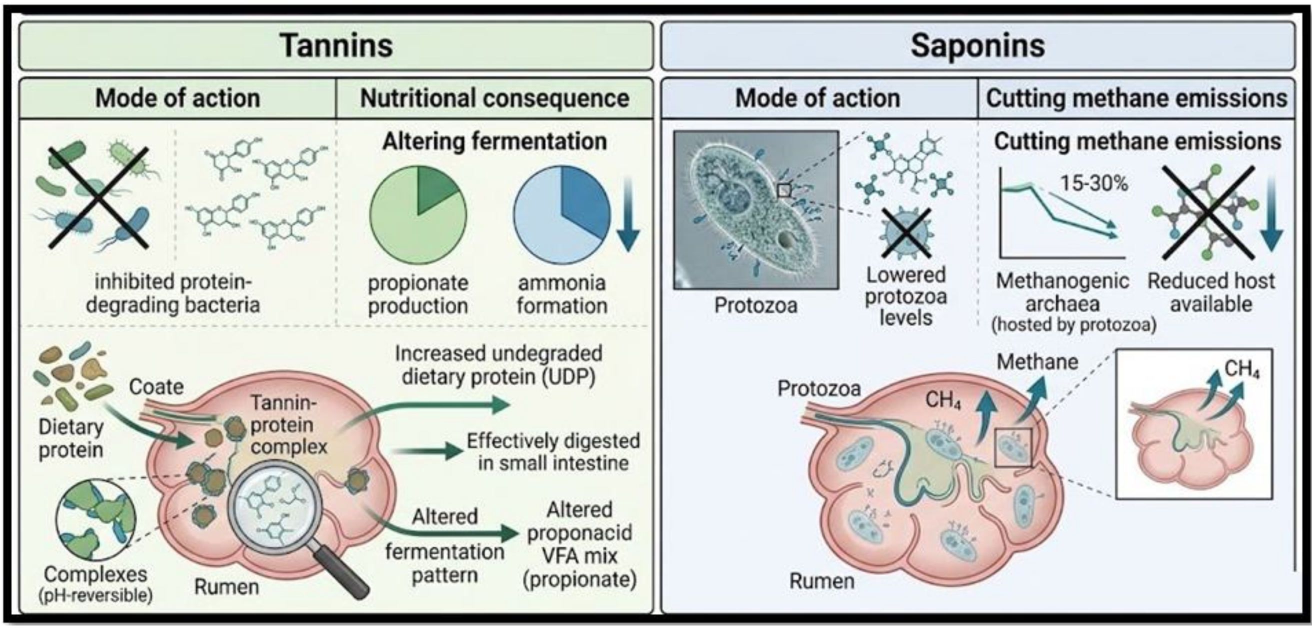


**Figure 2: Phytochemical impacts on rumen microbial ecology and fermentation patterns.**

**Table 3: Antinutritional factors (ANFs) in major tree fodder species**

| Tree fodder species | Tannins (%) | Saponins (%) | Oxalates (%) | Phytates (%) | References |
|---|---|---|---|---|---|
| *L. leucocephala* | 1.5-4.0 | 0.5-1.5 | 0.3-0.8 | 0.8-1.2 | D'Mello, 1992; Shelton and Brewbaker, 1994 |
| *G. sepium* | 2.0-5.0 | 1.0-2.5 | 0.4-1.0 | 0.6-1.0 | Roshetko and Gutteridge, 1990 |
| *S. grandiflora* | 0.8-2.5 | 1.5-3.0 | 0.5-1.2 | 0.7-1.1 | Evans and Rotar, 1987; Gutteridge and Shelton, 1994 |
| *M. oleifera* | 1.2-3.5 | 0.5-1.5 | 0.2-0.6 | 0.5-0.9 | Makkar and Becker, 1997; Anwar *et al.*, 2007 |
| *M. alba* | 0.5-1.5 | 0.3-0.8 | 0.2-0.5 | 0.4-0.7 | Sánchez, 2002; Singhal *et al.*, 2010 |
| *F. benghalensis* | 3.5-7.0 | 0.8-2.0 | 0.6-1.5 | 1.0-1.5 | Chandrasekar *et al.*, 1990; Singh and Prabhakar, 1985 |
| *A. indica* | 4.0-8.0 | 1.5-3.5 | 0.8-1.8 | 1.2-1.8 | Koul *et al.*, 1990; Singh and Sastry, 1981 |
| *A. nilotica* | 5.0-12.0 | 1.0-2.5 | 0.5-1.2 | 1.0-1.6 | Singh *et al.*, 2009; Dube *et al.*, 2000 |
| *A. lebbeck* | 3.5-8.0 | 1.2-2.8 | 0.6-1.4 | 0.9-1.4 | Duke, 1983; Krisnachinda and Limpinuntana, 1992 |
| *H. binata* | 6.0-10.0 | 0.8-2.0 | 0.7-1.5 | 1.1-1.7 | Singh and Mishra, 1988; Pathak and Kumar, 1982 |
| *P. juliflora* | 4.5-9.0 | 1.5-3.0 | 0.5-1.3 | 1.0-1.5 | Simpson, 1977; Felker and Bandurski, 1979 |
| *E. indica* | 2.5-5.5 | 1.8-3.5 | 0.4-1.0 | 0.8-1.3 | Westley and Powell, 1993; Little and Skolmen, 1989 |

## 5. Anti-nutritional factors (ANFs) in tree fodders

### 5.1 Major ANFs found in tree fodders

Despite the potential benefits of tree fodder regarding nutritional and phytomedicinal value, several anti-nutritional elements may restrict its use, besides causing health complications to livestock at high concentrations (Table 3).

#### 5.1.1 Condensed tannins

At concentrations above 5-6% DM, condensed tannins (CT) immensely decrease voluntary feed intake because of astringency and post-ingestive malaise (Makkar, 2003). Higher CT (>6% DM) reduces protein and dry matter digestibility (DMD) by 20-40%, decreases mineral bioavailability through chelation, and may damage intestinal mucosa (Mueller-Harvey, 2006).

#### 5.1.2 Mimosine

Mimosine is a harmful non-protein amino acid appearing only in Leucaena species at 2-7% DM (D'Mello and Acamovic, 1989). Mimosine and its metabolite 3-hydroxy-4(1H)-pyridone (3,4-DHP) lead to toxicity symptoms, including hair loss, goitre, weight loss, and low reproduction (Jones, 1994). Ruminants with the right rumen bacteria (*Synergetes jonesii*) can detoxify 3,4-DHP, although this organism is not present in all geographical areas (Jones and Megarrity, 1986).

#### 5.1.3 Oxalates

Oxalates are seen in soluble and insoluble forms in most tree fodders, with overall oxalate levels reaching above 10% DM in certain species. Soluble oxalates are quickly taken up and may bind calcium, forming insoluble calcium oxalate crystals in the kidney and urinary passage that can cause urolithiasis and renal injury (Rahman and Kawamura, 2011).

#### 5.1.4 Phytates

Phytates (inositol hexaphosphate) are storage compounds of phosphorus found at 0.5-2% DM in tree fodders (Kumar and D'Mello, 1995). Phytates bind divalent cations like calcium, zinc, iron, and magnesium, decreasing the bioavailability of minerals by 30-50%.

#### 5.1.5 Cyanogenic glycosides

Cyanogenic glycosides occur in several tree species at 0.1-1% DM but sometimes higher (Vetter, 2000). When plant tissue is damaged or digested, these compounds release hydrogen cyanide (HCN), which inhibits cellular respiration by attaching to cytochrome oxidase. Acute cyanide toxicity leads to rapid breathing, muscle trembling, convulsions, and death, while chronic low-dose exposure inhibits growth and may cause thyroid disease.

### 5.2 Duality of ANFs: Limitation or advantage

A crucial paradigm shift has occurred in the study of ANFs: most compounds considered anti-nutritional at high levels can produce beneficial effects at low to moderate dosages. This dose-dependency produces a U-shaped or inverted U-shaped response curve for numerous outcomes (Patra and Saxena, 2010). At moderate concentrations (2-4% DM), tannins positively prevent ruminal breakdown of dietary protein, enhance amino acid absorption, decrease methane generation, and show anthelmintic action leading to enhanced animal performance (Min and Hart, 2003). This dose-relation means that exploiting and advantageously utilising tree fodders requires careful management of inclusion rates, generally limiting tree fodder to 15-40% of total diet DM (Makkar, 2003).

### 5.3 Effect of ANFs on livestock physiology

ANFs affect voluntary feed intake through several mechanisms. Tannins induce astringent properties and bitterness, provoking taste aversion (Provenza, 1996). High tannin levels decrease protein digestibility by up to 40% (Makkar, 2003). Phytates and oxalates decrease the bioavailability of calcium, phosphorus, zinc, and iron by 30-60% (Kumar and D'Mello, 1995). ANF at excessive levels leads to different pathologies, including mimosine-induced thyroid hyperplasia (goitre), alopecia, infertility, and growth retardation (Jones, 1994), as well as cyanide toxicity leading to acute intoxication or long-term thyroid malfunctions (Vetter, 2000).

## 6. Mitigation and management of ANFs

### 6.1 Processing techniques

ANFs can be minimised by different physical, chemical, and biological pretreatment processes. Sun-drying may reduce tannin bioactivity by 15-30% through oxidation and polymerisation (Singh and Singh, 2003). Water-washing can extract soluble tannins and mimosine with removal rates of 30-60% depending on time, temperature, and water changes (D'Mello and Fraser, 1981). Heat treatment (boiling, steaming, autoclaving) inactivates protease inhibitors and toxins like cyanogenic glycosides (Makkar, 2003). Boiling can decrease mimosine levels in Leucaena by 40-70%. Ensiling tree fodder with molasses or grain reduces tannin activity by 20-40% and successfully detoxifies cyanogenic glycosides (Melesse *et al.*, 2017).

### 6.2 Feed dilution and supplementation

Strategic supplementation can counter particular ANF effects. Amino acid supplements, including high-tannin tree fodder plus methionine or sulphur-containing amino acids, can replace cysteine reserves lost to mimosine metabolism (Jones, 1994). Calcium supplementation is used to prevent oxalate toxicity, and mineral supplements containing zinc, iron, and calcium counteract mineral antagonism from phytates and oxalates (Kumar and D'Mello, 1995). The most viable solution is dilution by mixing high-ANF tree fodders with low-ANF forage and restricting tree fodder to 15-40% of total diet DM (Makkar, 2003).

### 6.3 Species-specific feeding strategies

Ruminants normally withstand higher ANF levels than non-ruminants because of microbial detoxification in the rumen. Cattle and buffalo are more tolerant ofmimosine when rumen bacteria for 3,4-DHP detoxification are present (Jones and Megarrity, 1986). Small ruminants (sheep, goats) exhibit better browsing patterns and greater tolerance to tannins because they have higher levels of tannin-binding salivary proteins (Silanikoveet *al.*, 2001). Animals progressively introduced to tree fodders become more tolerant through the development of better rumen microbial adaptation, detoxification enzyme systems, and diet selection (Lowry *et al.*, 1996). Rotational feeding, alternating high and low ANF feeds, inhibits build-up of toxic metabolites and allows voluntary consumption (Provenza, 1996).

## 7. Comprehensive effects on animal health

### 7.1 Gastrointestinal and metabolic health

Properly administered tree fodder supplementation tends to improve rumen ecology and gut wellbeing. Moderate tannin levels selectively adjust rumen microbiota by lowering protein degradation and ammonia generation, stabilising fiber-digesting populations (Patra and Saxena, 2011). Studies involving sheep fed tanniferous tree fodder demonstrated higher microbial protein flow in the duodenum relative to tannin-free diets (Min and Hart, 2003). The phytochemicals in tree fodders also decrease the content of pathogenic bacteria in the intestine, reducing the occurrence of enteritis and diarrhea, especially among young animals (Patra and Saxena, 2009).

### 7.2 Disease resistance and parasite control

Among the highest potential applications of tree fodder phytomedicine is improved disease resistance and parasite control. Gastrointestinal nematodes generate an estimated loss of over 3 billion dollars every year globally (Hoste *et al*., 2006). Studies involving *C. calothyrsus, G. sepium,* and different *Acacia* spp. have displayed 30-60% changes in fecal egg count and 25-50% changes in worm burden reduction in sheep and goats on tannin-free diets (Athanasiadou *et al*., 2007). It has been found that the mean incidence of mastitis in dairy cows was lower with *Moringa* leaf supplementation, which can be explained by antimicrobial flavonoids and isothiocyanates (Nouman *et al*., 2014).

### 7.3 Immune capacity and stress reduction

Studies in livestock fed saponin diets demonstrated that antibody titers to vaccinations increased 30-60% relative to controls (Cheeke, 2000). Polysaccharides in *Moringa* and other species cause the development of macrophages, increasing phagocytosis and clearance of pathogens (Gupta *et al*., 2010). Oxidative stress, endemic in intensive livestock production due to high metabolic rate, heat stress, and poor-quality diets, can be mitigated by antioxidant compounds in tree fodders that improve the antioxidant defence system of animals (Surai, 2014). A study using dairy cows fed with *Moringa* in hot seasons depicted that milk yield remained unchanged and reproductive parameters were better than supplemented controls (Nouman *et al*., 2014).

## 8. Effects on animal productivity and performance

### 8.1 Growth and feed conversion ratio

Scores of studies have observed better growth rates of cattle, sheep, goats, and other animals fed on tree fodders as opposed to low-quality basal diets. In Ethiopia, sheep receiving *Sesbania sesban* (30% of DM intake) attained 50-80 g/day as compared to 15-25 g/day in animals fed solely on wheat straw (Melesse *et al*., 2017). Goats fed Leucaena supplementation (40% of diet DM) gained 60-90 g/day compared to 20-35 g/day controls (Singh *et al*., 2017). Research results have shown a 15-30% increase in feed conversion ratios on tree fodder relative to low-quality basal feeds (Devendra, 1992).

### 8.2 Milk yield and milk quality

Tree fodder supplementation has demonstrated positive outcomes in milk production among dairy cattle, buffalo, sheep, and goats, especially during dry seasons. Indian studies proved that leucaena supplementation made crossbred cows produce 12-25% more milk than those not provided with the supplement (Singh *et al*., 2017). Moringa supplementation has shown reports of 10-20% milk yield increment, and enhanced milk composition with increased beta-carotene and vitamin A (Nouman *et al*., 2014). Economic studies consistently present promising results of tree fodder supplementation of dairy animals, because higher milk sales cover the expenses of supplementation (Franzel *et al*., 2014).

### 8.3 Reproductive performance

Supplementary feeding with tree fodder can enhance reproductive outcomes. Research has described higher rates of conception, fewer days to first estrus postpartum, and shorter calving intervals among cattle fed leguminous tree fodders compared to unsupplemented controls (Devendra, 2012). However, over consumption of certain tree fodders can hamper reproduction. High intake of Leucaena, leading to mimosine toxicity, can lower fertility in animals not adapted to Leucaena (Jones, 1994).

### 8.4 Carcass characteristics and meat quality

Generally, there is improvement in carcass weight, dressing percentage, and lean meat proportion with proper tree fodder supplementation over unsupplemented low-quality diets (Mahgoub *et al*., 2005). Antioxidant compounds of tree fodders have the potential to elevate meat oxidative stability, increasing shelf life. Studies indicated less lipid oxidation and higher color stability in meat from animals fed with antioxidant-containing tree fodders compared to traditional diets (Surai, 2014).

## 9. Future needs

### 9.1 Standardised assay for ANFs and phytochemicals

Presentday systems to measure ANFs and phytochemicals are not standardised among different laboratories, challenging comparison of results and establishment of standard safe inclusion levels (Makkar, 2003). The formation of standardised and available analytical protocols is essential to produce reliable data. Moreover, in the majority of studies, total ANF content is measured rather than bioactive fractions, which may exaggerate actual threats.

### 9.2 Safe inclusion levels for various livestock species

Although, it is generally considered that 15-40% of tree fodder should be included in the diet, species-specific and compound-specific safe inclusion levels are yet to be established (Makkar, 2003). Studies are required to determine accurate dose-response associations of major ANFs in livestock species, considering variables such as age, physiological condition, and level of production.

### 9.3 Long-term health and productivity trials

The majority of tree fodder studies have focused on short-term investigations. There is a dearth of long-term research on the cumulative impacts of continuous consumption of tree fodder on animal health, productivity, and welfare across several production cycles (Singh *et al*., 2017). Multigenerational studies evaluating reproductive performance, offspring health, and possible adaptive responses are needed.

### 9.4 Mechanistic understanding

Phenotypic impacts of tree fodders have received extensive documentation, but mechanistic knowledge is not exhaustive.

Molecular studies including transcriptomics, proteomics, and metabolomics could clarify the effects of phytochemicals on gene expression, protein production, and metabolic processes (Patra, 2010).

### 9.5 Nutraceutical and functional feed development

The phytomedicinal use of tree fodders implies the possibility of developing functional livestock nutritional remedies or nutraceuticals addressing particular biomedical issues such as parasitism, metabolic diseases, or stresses (Patra and Saxena, 2010). Extraction, concentration, and formulation of bioactive compounds would lead to products with applications beyond normal feeding.

### 9.6 Socioeconomic and adoption research

Technical potential needs to be supplemented by knowledge of adoption barriers and facilitators. Research on the economics, labour requirements, cultural implications, and institutional support systems for adopting tree fodder use is needed (Franzel *et al*., 2014). Participatory research involving farmers in assessing and modifying fodder systems can enhance relevance and uptake.

### 9.7 Interactions with climate change

Research into the effects of temperature, precipitation, and high atmospheric $CO_2$ on the fodder quantity, composition, and ANF content of tree species is required to inform species selection under future climatic conditions (Thornton *et al*., 2009).

## 10. Conclusion

As multifunctional resources, tree fodders span the food-feed-medicine continuum with significant prospects for improving livestock productivity, health, and system sustainability. This review has incorporated evidence of nutritional benefits presented by tree fodder in comparison with conventional feeds, especially regarding protein, minerals, and vitamins. The versatile phytochemical compounds in tree fodders possess antimicrobial, anthelmintic, antioxidant, and immunomodulatory effects that could decrease disease burden, enhance animal health, and potentially decrease the use of synthetic veterinary pharmaceuticals.

However, to achieve these advantages, anti-nutritional factors must be wisely controlled. The dose-response characteristics of phytochemical action mean that positive effects are found at intermediate dosages, while negative effects occur at high dosages. The benefits and risks can be optimised by strategic supplementation at 15-40% of dietary dry matter, with proper processing, supplementation, and species selection. Safe and productive use of tree fodder will be further improved through standardised assessment tools, species-specific feeding recommendations, and better-adapted tree species.

With the global challenges of climate change, resource depletion, and the need to minimise synthetic production inputs in livestock production, the use of tree fodder presents a nature-based solution aligned with agroecological ideals. Being integrated into diversified farming systems, tree fodders can achieve several goals: enhanced livestock health and nutrition, increased farm productivity, biodiversity conservation, and environmental resilience. Future studies in areas of long-term effects, mechanistic knowledge, and climate change interactions will further enhance the scientific basis of tree fodder utilisation.

For practical application, farmers and livestock managers are advised to incorporate tree fodders at 15-40% of total dietary dry matter, depending on species and animal class. High-tannin species such as Acacia and *L. leucocephala* should be restricted to >30% DM and, where possible, wilted or ensiled prior to feeding to reduce anti-nutritional factor (ANF) load. Rotational grazing and gradual introduction of tree fodder allow rumen microbiota to adapt and improve tolerance. Species with lower ANF profiles and high nutritional value, such as *M. oleifera* and *G. sepium,* are particularly recommended as year-round protein supplements during lean seasons. Mineral supplementation should accompany high-oxalate and high-phytate fodder species to prevent deficiencies. These evidence-based management practices can maximise the nutritional and phytomedicinal benefits of tree fodders while safeguarding animal health and productivity.

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## Conflict of interest

The authors declare no conflicts of interest relevant to this article.

## References

**Athanasiadou, S.; Kyriazakis, I.; Jackson, F. and Coop, R.L. (2007)**. Direct anthelmintic effects of condensed tannins towards different gastrointestinal nematodes of sheep: *In vitro* and *in vivo* studies. Veterinary Parasitology, **147**(1-2):64-74.

**Anwar, F.; Latif, S.; Ashraf, M. and Gilani, A.H.(2007).** *M. oleifera*: A food plant with multiple medicinal uses. Phytotherapy Research, **21**(1):17-25.

**Bakshi, M.P.S. and Wadhwa, M. (2004).** Evaluation of forest tree leaves of semi-hilly arid region as livestock feed. Asian-Australasian Journal of Animal Sciences, **17**(6):777-783.

**Bargavi S.;Baranidharan K.; Tilak M.; Revathi R.; Ganesan K.N.; Ragunath K.P.;Vijayabhama M.; Hemalatha P.; Ravi R.; Kabinesh V. and Suwethaasri D. (2025).** Nutrient-rich or anti-nutritional challenge? Evaluating Senna spectabilis (DC.) H.S. Irwin & Barneby for sustainable animal feed production. Plant Science Today, **12**(2):1-8. https://doi.org/10.14719/pst.7953

**Barry, T.N. and McNabb, W.C. (1999)**. The implications of condensed tannins on the nutritive value of temperate forages fed to ruminants. British Journal of Nutrition, **81**(4):263-272.

**Brewbaker, J.L. (1986).** Leguminous trees and shrubs for Southeast Asia and the South Pacific. In: G.J. Blair, D.A. Ivory, and T.R. Evans (Eds.), Forages in Southeast Asian and South Pacific Agriculture (pp:43-50). ACIAR Proceedings No. 12.

**Chandrasekar, B.; Bajpai, M.B. and Mukherjee, S.K. (1990).** Studies on *Ficus benghalensis*. Ancient Science of Life, **10**(1):1-8.

**Cheeke, P.R. (2000).** Actual and potential applications of *Yucca schidigera* and *Quillaja saponaria* saponins in human and animal nutrition. Journal of Animal Science, **77**(E-Suppl):1-10.

**Cowan, M.M. (1999).** Plant products as antimicrobial agents. Clinical Microbiology Reviews, **12**(4):564-582.

**Cushnie, T.P.T. and Lamb, A.J. (2005).** Antimicrobial activity of flavonoids. International Journal of Antimicrobial Agents, **26**(5):343-356.

**Devendra, C. (1992).** Nutritional potential of fodder trees and shrubs as protein sources in ruminant nutrition. In: A.W. Speedy and P.L. Pugliese (Eds.), Legume Trees and Other Fodder Trees as Protein Sources for Livestock (pp:95-113). FAO Animal Production and Health Paper 102.

**Devendra, C. (2012).** Rainfed areas and animal agriculture in Asia: the wanting agenda for transforming productivity growth and rural poverty. Asian-Australasian Journal of Animal Sciences, **25**(1):122-142.

**D'Mello, J.P.F. (1992).** Chemical constraints to the use of tropical legumes in animal nutrition. Animal Feed Science and Technology, **38**(2-3):237-261.

**D'Mello, J.P.F. and Acamovic, T. (1989).** *L. leucocephala* in poultry nutrition-a review. Animal Feed Science and Technology, **26**(1-2):1-28.

**D'Mello, J.P.F. and Fraser, K.W. (1981).** The composition of leaf meal from *L. leucocephala*. Tropical Science, **23**:75-78.

**Dube, A.; Sharma, N. and Sharma, A.K. (2000).** *A. nilotica*: A tree for multipurpose uses. Indian Forester, **126**(5):487-494.

**Duke, J.A. (1983).** Handbook of Energy Crops. Purdue University, Center for New Crops and Plant Products.

**Evans, D.O. and Rotar, P.P. (1987).** Sesbania in agriculture. Westview Tropical Agriculture Series, Boulder, Colorado.

**Felker, P. and Bandurski, R.S. (1979**). Uses and potential uses of leguminous trees for minimal energy input agriculture. Economic Botany, **33**(2):172-184.

**Franzel, S.; Carsan, S.; Lukuyu, B.; Sinja, J. and Wambugu, C. (2014).** Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. Current Opinion in Environmental Sustainability, **6**:98-103.

**Fuglie, L.J. (2001).** The Miracle Tree: *M. oleifera*: Natural Nutrition for the Tropics. Church World Service, Dakar, Senegal.

**Gupta, A.; Gautam, M.K.; Singh, R.K.; Kumar; M.V., Rao; C.V.; Goel, R.K. and Anupurba, S. (2010).** Immunomodulatory effect of *M. oleifera* Lam. extract on cyclophosphamide induced toxicity in mice. Indian Journal of Experimental Biology, **48**(11):1157-1160.

**Gutteridge, R.C. and Shelton, H.M. (1994).** Forage Tree Legumes in Tropical Agriculture. CAB International, Wallingford, UK.

**Hess, H.D.; Monsalve, L.M.; Lascano, C.E.; Carulla, J.E.; Diaz, T.E. and Kreuzer, M. (2003).** Supplementation of a tropical grass diet with forage legumes and *Sapindus saponaria* fruits: Effects on *in vitro* ruminal nitrogen turnover and methanogenesis. Australian Journal of Agricultural Research, **54**(7):703-713.

**Hoste, H.; Jackson, F.; Athanasiadou, S.; Thamsborg, S.M. and Hoskin, S.O. (2006).** The effects of tannin-rich plants on parasitic nematodes in ruminants. Trends in Parasitology, **22**(6):253-261.

**Jones, R.J. (1994).** Management of anti-nutritive factors-with special reference to leucaena. In: J.P. Gutteridge and H.M. Shelton (Eds.), Forage Tree Legumes in Tropical Agriculture (pp:216-231). CAB International.

**Jones, R.J. and Megarrity, R.G. (1986).** Successful transfer of DHP-degrading bacteria from Hawaiian goats to Australian ruminants to overcome the toxicity of Leucaena. Australian Veterinary Journal, **63**(8):259-262.

**Kaitho, R.J.; Umunna, N.N.; Nsahlai, I.V.; Tamminga, S.; Van Bruchem, J.; Hanson, J.and Van De Wouw, M. (1998).** Palatability of multipurpose tree species: effect of species and length of study on intake and relative palatability by sheep. Agroforestry Systems, **43**(1-3):109-116.

**Koul, O.; Isman, M.B. and Ketkar, C.M. (1990).** Properties and uses of neem, *A. indica*. Canadian Journal of Botany, **68**(1):1-11.

**Krisnachinda, K. and Limpinuntana, V. (1992**). Forage value of multipurpose trees. Thai Journal of Agricultural Science, **25**(2):125-135.

**Kumar, R. and D'Mello, J.P.F. (1995).** Anti-nutritional factors in forage legumes. In: J.P.F. D'Mello and C. Devendra (Eds.), Tropical Legumes in Animal Nutrition (pp. 95-133). CAB International.

**Kumar, B.M. and Singh, A.K. (2005).** Agroforestry: Scope and opportunities. In: P.K.R. Nair, B.M. Kumar, and V.D. Nair (Eds.), Agroforestry for Ecosystem Services and Environmental Benefits (pp:1-12). Springer, Dordrecht.

**Little, E.L. and Skolmen, R.G. (1989).** Common Forest Trees of Hawaii (Native and Introduced). USDA Forest Service, Agriculture Handbook 679.

**Lowry, J.B.; Prinsen, J.H., and Burrows, D.W. (1996).** *A. lebbeck*: A promising forage tree for semiarid regions. In: H.M. Shelton, C.M. Piggin, and J.L. Brewbaker (Eds.), Forage Tree Legumes in Tropical Agriculture (pp:75-83). CAB International.

**Mahajan, S.G.; Banerjee, A.; Chauhan, B.F.; Padh, H.; Nivsarkar, M.and Mehta, A.A. (2007).** Inhibitory effect of n-butanol fraction of *M. oleifera* Lam. seeds on ovalbumin-induced airway inflammation in a guinea pig model of asthma. International Journal of Toxicology, **26**(6):473-480.

**Mahgoub, O.; Kadim, I.T.; Tageldin, M.H.; Al-Marzooqi, W.S.; Khalaf, S.Q.and Al-Amri, I.S. (2005).** Clinical profile of sheep fed non-conventional feeds containing phenols, condensed tannins, sulphur and oxalates. Small Ruminant Research, **59**(2-3):203-215.

**Makkar, H.P.S. and Becker, K. (1997).** Nutrients and antiquality factors in different morphological parts of the *M. oleifera* tree. Journal of Agricultural Science, **128**(3):311-322.

**Makkar, H.P.S. (2003).** Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds. Small Ruminant Research, **49**(3):241-256.

**Makkar, H.P.S. and Becker, K. (1996).** Nutritional value and antinutritional components of whole and ethanol extracted *M. oleifera* leaves. Animal Feed Science and Technology, **63**(1-4):211-228.

**Melesse, A.; Steingass, H.; Schollenberger, M. and Rodehutscord, M. (2017).** Screening of common tropical grass and legume forages in Ethiopia for their nutrient composition and methane production profile *in vitro*.

**Min, B.R. and Hart, S.P. (2003).** Tannins for suppression of internal parasites. Journal of Animal Science, **81**(E-Suppl 2):E102-E109.

**Mueller-Harvey, I. (2006).** Unravelling the conundrum of tannins in animal nutrition and health. Journal of the Science of Food and Agriculture, **86**(13):2010-2037.

**Nair, P.K.R. (2012).** Carbon sequestration studies in agroforestry systems: a reality-check. Agroforestry Systems, **86**(2):243-253.

**Nouman, W.; Siddiqui, M.T.; Basra, S.M.A.; Farooq, H.; Zubair, M.and Gull, T. (2014).** Biomass production and nutritional quality of *M. oleifera* as a field crop. Turkish Journal of Agriculture and Forestry, **38**(4):1-10.

**Pan, M.H.; Lai, C.S. and Ho, C.T. (2010).** Anti-inflammatory activity of natural dietary flavonoids. Food and Function, **1**(1):15-31.

Pandey, C.B. and Roy, M.M. (2011). Tree fodder for sustainable animal production in India. Indian Journal of Animal Sciences, 81(5):485-497.

Pathak, P.S. and Kumar, N. (1982). Fodder production from *H. binata* in semi-arid regions. Indian Journal of Forestry, 5(3):201-206.

Patra, A.K. (2010). Meta-analyses of effects of phytochemicals on digestibility and rumen fermentation characteristics associated with methanogenesis. Journal of the Science of Food and Agriculture, 90(15):2714-2729.

Patra, A.K. and Saxena, J. (2009). Dietary phytochemicals as rumen modifiers: A review of the effects on microbial populations. Antonie van Leeuwenhoek, 96(4):363-375.

Patra, A.K. and Saxena, J. (2010). A new perspective on the use of plant secondary metabolites to inhibit methanogenesis in the rumen. Phytochemistry, 71(11-12):1198-1222.

Patra, A.K. and Saxena, J. (2011). Exploitation of dietary tannins to improve human health and animal productivity. Journal of the Science of Food and Agriculture, 91(1):24-37.

Provenza, F.D. (1996). Acquired aversions as the basis for varied diets of ruminants foraging on rangelands. Journal of Animal Science, 74(8):2010-2020.

Rahman, M.M. and Kawamura, O. (2011). Oxalate accumulation in forage plants: some agronomic, climatic and genetic aspects. Asian-Australasian Journal of Animal Sciences, 24(3):439-448.

Reed, J.D. (1995). Nutritional toxicology of tannins and related polyphenols in forage legumes. Journal of Animal Science, 73(5):1516-1528.

Roshetko, J.M. and Gutteridge, R.C. (1990). *G. sepium*: A multipurpose forage tree for humid tropics. NFTA NFT Highlights, NFTA 90-05. Winrock International, Morrilton, USA.

Sánchez, M.D. (2002). World distribution and utilization of mulberry and its potential for animal feeding. In: Mulberry for Animal Production (pp. 1-10). FAO Animal Production and Health Paper 147.

Salem, A.Z.M. and Smith, T. (2008). Plant secondary compounds in browse legumes and their effects on digestibility and fermentation of the diet in ruminants. Feed Science and Technology, 144(1-2):1-22.

Scalbert, A. and Williamson, G. (2000). Dietary intake and bioavailability of polyphenols. Journal of Nutrition, 130(8):2073S-2085S.

Shelton, H.M. and Brewbaker, J.L. (1994). *L. leucocephala*-the most widely used forage tree legume. In: Forage Tree Legumes in Tropical Agriculture (pp:15-29). CAB International.

Silanikove, N.; Perevolotsky, A. and Provenza, F.D. (2001). Use of tannin-binding chemicals to assay for tannins and their negative postingestive effects in ruminants. Animal Feed Science and Technology, 91(1-2):69-81.

Simpson, B.B. (1977). Mesquite, its biology in two desert ecosystems. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania.

Singh, A.K. and Prabhakar, A.K. (1985). Fodder value of *F. benghalensis* in Northern India. Indian Journal of Animal Sciences, 55(5):345-348.

Singh, B.N.; Singh, B.R.; Singh, R.L.; Prakash, D.; Dhakarey, R.; Upadhyay, G. and Singh, H.B. (2009). Oxidative DNA damage protective activity, antioxidant and anti-quorum sensing potentials of *M. oleifera*. Food and Chemical Toxicology, 47(6):1109-1116.

Singh, N. and Sastry, M.S. (1981). Antimicrobial activity of neem oil. Indian Journal of Pharmacology, 13:102-106.

Singh, P. and Mishra, M.K. (1988). Tree fodder resources in semi-arid zones. Agroforestry Systems, 6(1):45-52.

Singh, P.; Kumar, R.; Sabapathy, S.N. and Bawa, A.S. (2017). Functional and edible uses of soy protein products. Comprehensive Reviews in Food Science and Food Safety, 7(1):14-28.

Singhal, B.K.; Khan, M.A.; Dhar, A.; Baqual, F.M. and Bindroo, B.B. (2010). Approaches to industrial exploitation of mulberry (Mulberry spp.,) fruits. Journal of Fruit and Ornamental Plant Research, 18(1):83-99.

Singh, B. and Todaria, N.P. (2012). Medicinal value of trees and shrubs of Uttarakhand Himalaya. Indian Forester, 138(1):85-91.

Singh, A.K. and Singh, J. (2003). Drying characteristics of garlic (*Allium sativum*). Journal of Food Engineering, 58(3):241-246.

Stewart, J.L.; Allison, G.E. and Simons, A.J. (2019). *G. sepium*: Genetic resources for farmers. Tropical Forestry Papers, 33. Oxford Forestry Institute.

Surai, P.F. (2014). Polyphenol compounds in the chicken/animal diet: from the past to the future. Journal of Animal Physiology and Animal Nutrition, 98(1):19-31.

Thornton, P.K.; van de Steeg, J.; Notenbaert, A. and Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agricultural Systems, 101(3):113-127.

Tolera, A.; Khazaal, K. and Orskov, E.R. (1997). Nutritive evaluation of some browse species. Animal Feed Science and Technology, 67(2-3):181-195.

Vetter, J. (2000). Plant cyanogenic glycosides. Toxicon, 38(1):11-36.

Westley, S.B. and Powell, M.H. (1993). Erythrina in the New and Old Worlds. NFTA Special Publication 92-01, Winrock International, Arkansas.


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