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Research article

Nutritive value of foliage from multipurpose tree species in drought-prone southern India

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Abstract

A study was conducted to assess the nutritional value of foliage of fourteen multipurpose tree species from the drought-prone southern semi-arid regions of India, with the aim of evaluating their potential as livestock feed during lean period. The total ash content in the foliage ranged from 6.25% in *Tamarindus indica* to 19.08% in *Salvadora persica*. Crude protein (CP) content varied significantly among species, with *Morus alba* exhibiting the highest CP (19.48%), while *T. indica* had the lowest (5.16%). The foliage of *Ficus virens* exhibited the highest carbohydrate content, whereas *Leucaena leucocephala* had the lowest. Crude fiber content was lower in *Leucaena leucocephala*, *Moringa oleifera*, *Sesbania grandiflora*, and *Azadirachta indica* compared to other species. With the exception of *T. indica*, all species had CP levels above 7%, meeting the minimum protein requirement for ruminal cellulolytic bacteria. Calcium content ranged from 75.64 mg in *Gliricidia sepium* to 189.89 mg in *S. persica*, while magnesium content varied from 7.23 mg in *Gliricidiasepium* to 38.80 mg in *Crescentia cujete*. *M. oleifera* foliage was particularly rich in iron (2.42 mg) and zinc (0.26 mg). Lignin content was high in *A. indica*, *M. alba*, *S. grandiflora*, and *S. persica*. Condensed tannin (CT) and total phenol (TP) contents varied significantly among the tree foliage. Total digestible nutrients (TDN), non-fiber carbohydrates (NFC) and forage nutritive value (FNV) also differed significantly among tree species. *S. grandiflora* had the highest TDN, while *T. indica* had the lowest. *M. oleifera* foliage showed the highest *in vitro* true digestibility (IVTD) and metabolizable energy (ME). The forage nutritive value (FNV) ranged from 14.51 in *T. indica* to 36.22 in *L. leucocephala*. Overall, foliage from these trees shows potential as an alternate nutritious fodder supplement during the lean period.

Keywords: Crude protein, Foliage, Forage nutritive value, *In-vitro* true digestibility, Tree species

Introduction

Livestock is a vital component of the rural agricultural economy and plays a significant role in poverty alleviation for many smallholder farmers in India. Low quality and limited availability of feeds are the major constraints in the sustenance of livestock productivity among smallholder farmers (Ayantunde *et al*., 2005). The scarcity of conventional feeds led to the exploration of alternative feed sources as forage options like legume feeding were found to be costly and limited cultivation by livestock farmers (Rana *et al*., 2006; Ganai *et al*., 2009). One such alternative is the use of leaf fodder from tree species, which are widely recognized as emergency feedstuffs, particularly during summer. These trees are valued for the high protein, soluble carbohydrate, mineral, and vitamin content of their leaves (Azim *et al*., 2002). Additionally, the deep tap root systems of the tree species allow them to maintain green phytomass late into the season when the herbaceous layer has dried out (Datt *et al*., 2008; Soni *et al*., 2016). In many parts of the world, particularly in the semi-arid regions of tropical countries like India, browsing trees and shrubs plays a crucial role in feeding and meeting the nutrient requirements of the livestock, especially during the lean season (Ramana, 2018).

Tree leaves and pods have been traditionally used as a source of feed for livestock in Asia, Africa and the Pacific and serve as protein banks to supplement grass or crop residues in the dry season (Bhatta *et al*., 2005). Tree fodder is particularly important in arid and semi-arid regions like Ananthapuramu, where trees remain a reliable source of nutrition for livestock during droughts and dry seasons and most of the tree species could potentially be useful as protein banks to supplement grass or crop residues in dry seasons (Ramana *et al*., 2000). Local farmers do possess valuable traditional knowledge about both native and alien species, but they are not well aware of their nutritional value. Hence, an attempt was made to study the nutritive value of foliage from 15 multipurpose tree species commonly exist on farm bunds in the drought-prone district of Ananthapuramu so as to use and recommend as an alternate nutritious fodder supplement to sustain livestock productivity, especially during lean season and drought period.

Materials and Methods

Study site: Leaves of fourteen multipurpose tree species were randomly collected during the Summer season from farm fields (naturally grown on the farm bunds) from all parts of the tree crown in and around the Ananthapuramu district in Andhra Pradesh state, one of the most drought-prone districts in the country.

Climatic characteristics: Multipurpose tree species were grown on farm fields in and around the Ananthapuramu district (14.68° N latitude and 77.60° E longitude and about 335 m above sea level) in Andhra Pradesh state. The climate is hot-arid with hot summers and very mild winters. The mean maximum air temperature varies from 29.6 (December) to 40.0°C (May), while the nighttime temperature varies from 16.3 (December) to 26.5°C (May). Annual long-term rainfall for the site is 594 mm, falling predominantly from June to November. The soils are sandy loam and shallow red soils. The soil pH is neutral to slightly acidic (pH 6.5–7.8).

***Chemical analysis*:** The foliage samples were initially air-dried and then oven-dried at 60 ± 5°C. Dried samples were ground to pass a 2-mm sieve in a Wiley Mill. They were analyzed for organic matter (OM), crude protein (CP) (AOAC, 1995) and cell wall constituents (Van Soest *et al*., 1991). Minerals such as K, Ca, Mg, Fe, Zn, Co, B, Al, Li and S were estimated (Hou and Jones, 2000) by Inductively Coupled Plasma Optical Emission Spectroscopy (Thermo Scientific iCAP 7000 Plus Series ICP-OES, USA). Tree leaf samples were also processed for polyphenolic fractions as total phenolics (TP) and condensed tannins (CT) following the methods (Folin Ciocalteu reaction) described by Makkar (2003). The *in-vitro* true digestibility (IVTD) was determined by incubation of feed samples in filter bags in a Daisy II incubator (ANKOM Technology Corp., Macedon, NY) with rumen inoculum and buffer in a 1:4 ratio for 48 hours under anaerobic conditions at 39°C as described by ANKOM Technology (2005) and Brons and Plaizier (2005). Metabolizable energy (ME) content is estimated by the following equation recommended by Nolan (2007).

$$ME = 0.17 \times IVTD - 2 \quad (1)$$

Where ME is metabolizable energy (MJ/kg DM) and IVTD is in-vitro true dry matter digestibility (%).

The forage nutritional value (FNV) index was calculated (Yao *et al*., 2022) as per the method based on CP content (g/100 g DM), ME (metabolizable energy (MJ/kg DM), IVTD (g/100 g DM), and NDF content (g/100 g DM) and calculated as

$$FNV = (CP + ME + 0.25\ IVTD) - 0.25\ NDF \quad (2)$$

The TDN (Total Digestible Nutrient) (g/100g DM) was calculated by the following equations from Linn and Martin (1989).

$$TDN = 88.9 - (ADF * 0.779) \quad (3)$$

The values in g/100 g DM were later converted into percent.

Statistical analysis: Data were analyzed by general linear model methodology using IBM SPSS statistics 20 software. Data were subjected to analysis of variance according to the procedure described by Wilkinson *et al*. (1996). All means reported in the text are the least square means. Values of $p \leq 0.05/0.01$ were considered as significant.

Results and Discussion

***Proximate nutrient content*:** Proximate nutrient content in the foliage of different multipurpose tree species was recorded (Fig 1). Mean total ash (TA) content varied from 19.08 to 6.25% in the foliage of different trees, with the highest ($p < 0.05$) in Salvadora persica and lowest in Tamarindus indica. The highest ($p < 0.05$) crude protein (CP) was observed in the foliage of Morus alba (19.48%), whereas the lowest ($p < 0.05$) in T. indica (5.16%). Ficus virens (3.93%) had maximum ($p < 0.05$), whereas Leucaena leucocephala (0.76%) had minimum total carbohydrates in the foliage. Ether extract content (%) was comparable among the foliage of different tree species. Lower crude fibre content was observed in the foliage of L. leucocephala (15.51%), Moringa oleifera (15.53%), Sesbania grandiflora (15.54%) and Azadirachta indica (15.64%) compared to the other tree species. Except for T. indica foliage, all other tree species foliage had CP above 7%, meeting the protein requirements and not limiting the microbial growth of ruminal cellulolytic bacteria (Venkatesh et al., 2024). The higher CP content provides a source of nitrogen for rumen microorganisms, supporting their growth and activity (Gaikwad et al., 2021). Lack of nutritious fodder often leads to a reduction in the productivity of livestock (Godfray et al., 2010). One of the major focuses of the integration of different tree species in the rainfed ecosystem is to maintain an appropriate nutritional balance for higher productivity that conjointly improves livestock performance (Salama et al., 2020).

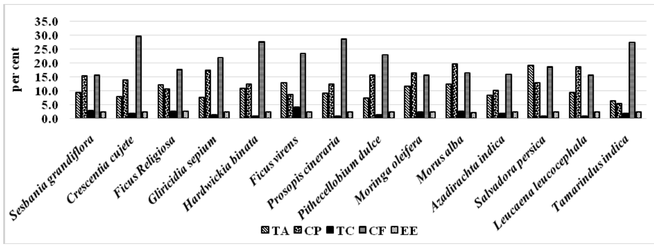

Fig 1. Mean proximate nutrient content (%) in foliage of different tree species (TA, total ash; CP, crude protein; TC, total carbohydrates; CF, crude fibre; EE, ether extract)

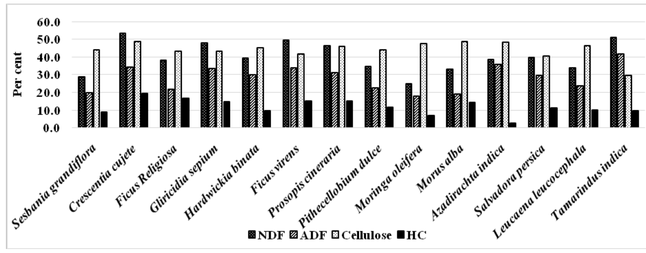

Fig 2. Mean fiber fractions content (%) in foliage of different tree species (NDF, neutral detergent fiber; ADF, acid detergent fiber; HC, hemicellulose)

***Fibre fractions*:** The mean NDF and ADF contents (Fig 2) were higher (p <0.05) in the foliage of *T. indica* (50.91 and 41.47%) and lower in *M. oleifera* (24.80 and 17.74%). The lowest cellulose content (p <0.05) was recorded in *T. indica* (29.34%) leaf materials. Hemi-cellulose content (%) in foliage was as low as 2.38 in *A. indica* and as high as 19.24 in *Crescentia cujete*. As the season progresses from rainy to summer, there was an observed increase in ADF and NDF levels, which can be attributed to the rise in cellulose, hemicellulose, and lignin contents in the leaves (Hussain and Durrani, 2009; Kokten *et al*., 2012) and this could be the reason for higher fiber fractions in the studied foliage as the foliage was collected during summer. Differences in protein and fiber contents for tree species and seasons were reported earlier (Singh *et al*., 2021).

***Mineral content*:** Mineral content of foliage (Table 1) varied significantly (p <0.05) among different multipurpose tree species. Calcium content in foliage ranged from 75.64 to 189.89 mg, with the highest in *S. persica* and the lowest in *Gliricidia sepium*. The magnesium content in the foliage was as low as 7.23 mg in *G. sepium* and as high as 38.80 mg in *Crescentia cujete*. The foliage of *M. oleifera* had higher (p <0.05) Fe (2.42 mg) and Zn (0.26 mg) content compared to the other tree species. *Pithecellobium dulce* (0.64 mg) had maximum (p <0.05), whereas *F. virens* (0.10 mg) had minimum (p <0.05) Mn content in the foliage. The findings are in agreement

Table 1. Mineral content in foliage of different tree species

Scientific Name	Ca (mg)	Mg (mg)	Fe (mg)	Zn (mg)	Mn (mg)
Sesbania grandiflora	111.17 ± 0.003^{i}	26.12 ± 0.003^{g}	0.99 ± 0.001^{i}	0.19 ± 0.006^{c}	0.60 ± 0.005^{c}
Crescentia cujete	106.84 ± 0.011^{k}	38.80 ± 0.007^{a}	1.04 ± 0.001^{h}	0.09 ± 0.002^{g}	0.17 ± 0.006^{k}
Ficus religiosa	131.73 ± 0.016^{d}	22.73 ± 0.004^{k}	0.49 ± 0.003^{k}	0.11 ± 0.002^{f}	0.18 ± 0.002^{j}
Gliricidia sepium	75.64 ± 0.003^{n}	7.23 ± 0.002^{n}	0.29 ± 0.001^{m}	0.17 ± 0.005^{d}	0.13 ± 0.007^{m}
Hardwickia binata	179.49 ± 0.001^{b}	27.29 ± 0.002^{e}	1.50 ± 0.001^{c}	0.25 ± 0.006^{b}	0.64 ± 0.007^{a}
Ficus virens	83.66 ± 0.005^{m}	19.42 ± 0.006^{m}	0.40 ± 0.003^{l}	0.08 ± 0.001^{h}	0.10 ± 0.001^{n}
Prosopis cineraria	120.89 ± 0.001^{f}	25.55 ± 0.002^{h}	2.36 ± 0.004^{a}	0.11 ± 0.002^{f}	0.58 ± 0.001^{d}
Pithecellobium dulce	113.59 ± 0.005^{g}	26.67 ± 0.012^{f}	1.13 ± 0.002^{g}	0.11 ± 0.007^{f}	0.63 ± 0.006^{b}
Moringa oleifera	107.56 ± 0.002^{j}	19.92 ± 0.008^{l}	2.42 ± 0.001^{a}	0.26 ± 0.002^{a}	0.20 ± 0.002^{i}
Morus alba	130.16 ± 0.016^{e}	23.26 ± 0.012^{i}	0.97 ± 0.001^{j}	0.14 ± 0.002^{e}	0.45 ± 0.002^{f}
Azadirachta indica	112.05 ± 0.006^{h}	36.73 ± 0.011^{c}	1.45 ± 0.004^{d}	0.09 ± 0.005^{g}	0.34 ± 0.001^{h}
Salvadora persica	189.89 ± 0.004^{a}	29.19 ± 0.006^{d}	1.69 ± 0.003^{b}	0.09 ± 0.001^{g}	0.38 ± 0.001^{g}
Leucaena leucocephala	133.67 ± 0.001^{c}	38.58 ± 0.010^{b}	1.14 ± 0.002^{f}	0.07 ± 0.001^{i}	0.56 ± 0.005^{e}
T. indica	89.33 ± 0.006^{l}	22.87 ± 0.005^{j}	1.36 ± 0.001^{e}	0.07 ± 0.001^{i}	0.15 ± 0.008^{l}
Mean	120.40	26.03	1.09	0.13	0.37
SEM	8.64	2.24	0.16	0.02	0.06
LSD	0.0005	0.0005	0.0001	0.0002	0.0003

Ca, Calcium; Mg, magnesium; Fe, iron; Zn, zinc; Mn, manganese. Data are given as mean ± SD. LSD, least square difference. The alphabetical letters given as superscript against each value indicates significant differences between tree species at p ≤0.05 if letters are different for different tree species, otherwise non-significant if having same letters with Navale *et al*. (2022), who observed variations in the mineral content in the leaves of different tree species. These differences in mineral composition among the tree species can be attributed to differences in maturity level, genetic makeup and soil fertility (Singh *et al*., 2009). Further, scarce rainfall and other climatic conditions tend to affect the photosynthetic process, resulting in lower forage yield and proximate and mineral composition changes in the foliage of tree species (Ravhuhali *et al*., 2022). The results revealed that most of the proximate components, fiber fractions, and mineral content in the top feeds were comparable to or better than those in conventional fodders. Similar findings were reported in the evaluated top feed species from Southern Gujarat (Parmar *et al*., 2022).

Anti-nutritional constituents' content: Higher (p <0.05) lignin content (Table 2) was observed in the foliage of *A. indica* (3.06%), *M. alba* (3.05%), *S. grandiflora* (3.00%) and *S. persica* (2.96%) compared to the other tree species. The highest silica content (p <0.05) was recorded in *S. persica* (17.07%), whereas the lowest was in *A. indica* (1.39%) leaf materials. All the tree species contained detectable amounts of CT and TP and varied widely in their concentration (Table 2). Mean TP content in the foliage ranged from 4.47 to 7.83%, with the highest in *M. alba* (7.83%) and lowest in *L. leucocephala* (4.47%). Condensed tannin (CT) content was significantly (p <0.05) higher (7.84%) in *F. religiosa*, while lowest (5.20%) in *L. leucocephala* leaf materials. Tannins precipitate proteins by hydrogen bonding and hydrophobic interactions (Haslam, 1974) to form stable complexes at rumen pH, which adversely affect protein and fiber digestion in the rumen (Palmer and Schlink, 1992) and thereby reduce protein availability to the animal (Woodward and Reed, 1989). Although the TP content was quite high in some species, the degradability seemed not to be much affected. CT protects labile plant proteins in the rumen and may consequently increase the supply of high-quality proteins entering the duodenum (Mangan, 1988). This indicates that in the foliage of some tree species, more protein could escape ruminal digestion and be digested in the lower part of the digestive tract (Driedger and Hatfield, 1972). Further, variation among species in TP and CT may be a result of physiological behaviur and genetic makeup, leading to differential seasonal changes in their phenol and tannin contents (Sahoo *et al*., 2016).

***Total digestible nutrients, in vitro true digestibility, metabolizable energy and forage nutritive value*:** The differences in total digestible nutrients (TDN) among different multipurpose tree species (Table 3) were significantly different with higher (p <0.05) total digestible nutrients (%) were observed in the foliage from *M. oleifera*

Table 2. Anti-nutritional constituents' content in foliage of different tree species

Scientific Name	Lignin (%)	Silica (%)	TP (%)	CT (%)
Sesbania grandiflora	3.00 ± 0.36^{b}	9.79 ± 0.58^{f}	5.63 ± 0.26^{i}	5.33 ± 0.15^{l}
Crescentia cujete	2.19 ± 0.32^{j}	2.83 ± 0.14^{k}	6.73 ± 0.25^{d}	6.47 ± 0.23^{g}
Ficus religiosa	1.96 ± 0.13^{k}	11.90 ± 0.01^{c}	6.64 ± 0.35^{e}	7.84 ± 0.02^{b}
Gliricidia sepium	2.33 ± 0.11^{g}	11.62 ± 0.27^{d}	4.85 ± 0.40^{l}	6.15 ± 0.08^{i}
Hardwickia Binata	2.24 ± 0.18^{i}	7.97 ± 0.59^{g}	6.25 ± 0.32^{g}	6.71 ± 0.15^{d}
Ficus virens	2.38 ± 0.08^{f}	16.14 ± 1.09^{b}	6.53 ± 0.20^{f}	6.92 ± 0.03^{c}
Prosopis cineraria	2.47 ± 0.42^{e}	7.97 ± 0.44^{g}	6.04 ± 0.30^{h}	6.51 ± 0.05^{f}
Pithecellobium dulce	2.30 ± 0.13^{h}	10.14 ± 0.04^{e}	7.82 ± 0.15^{b}	6.51 ± 0.06^{f}
Moringa oleifera	1.87 ± 0.07^{l}	4.33 ± 0.36^{i}	4.83 ± 0.12^{m}	6.62 ± 0.03^{e}
Morus alba	3.05 ± 0.40^{a}	2.50 ± 0.29^{l}	7.83 ± 0.15^{a}	7.92 ± 0.09^{a}
Azadirachta indica	3.06 ± 0.61^{a}	1.39 ± 0.13^{m}	5.24 ± 0.21^{j}	6.27 ± 0.07^{h}
Salvadora persica	2.96 ± 0.72^{c}	17.07 ± 0.75^{a}	6.87 ± 0.20^{c}	5.67 ± 0.03^{j}
Leucaena leucocephala	2.54 ± 0.32^{d}	5.78 ± 0.03^{h}	4.47 ± 0.32^{n}	5.20 ± 0.05^{m}
T. indica	2.35 ± 0.16^{g}	4.15 ± 0.48^{j}	4.86 ± 0.15^{k}	5.36 ± 0.05^{k}
Mean	2.48	8.11	6.04	6.39
SEM	0.11	1.32	0.29	0.22
LSD	0.02	0.03	0.02	0.01

TP, total phenolics; CT, condensed tannins. Data are given as mean ± SD. SEM, standard error of the mean; LSD, least square difference. The alphabetical letters given as superscript against each value indicate significant differences between tree species at P≤0.05 if letters are different for different tree species. Otherwise non-significant if having the same letters.

Table 3. *In-vitro* true digestibility (IVTD), metabolizable energy (ME), forage nutritive value (FNV), non-fiber carbohydrates (NFC) and total digestible nutrients (TDN) content in foliage of different tree species

Scientific Name	TDN (%)	NFC (%)	IVTD (%)	ME (MJ/kg DM)	FNV
Sesbania grandiflora	73.38 ± 0.49^{c}	44.29 ± 0.82^{b}	57.22 ± 3.25^{c}	7.73 ± 0.55^{c}	30.24 ± 1.22^{c}
Crescentia cujete	62.37 ± 0.72^{k}	23.00 ± 0.19^{n}	49.67 ± 5.17^{j}	6.44 ± 0.88^{j}	19.18 ± 2.25^{l}
Ficus religiosa	72.14 ± 0.62^{d}	36.87 ± 0.30^{e}	55.65 ± 9.17^{d}	7.46 ± 1.56^{d}	22.22 ± 3.85^{g}
Gliricidia sepium	62.78 ± 0.98^{j}	25.14 ± 0.05^{m}	52.36 ± 0.28^{g}	6.90 ± 0.05^{g}	25.42 ± 0.16^{f}
Hardwickia binata	65.48 ± 0.54^{h}	35.22 ± 1.04^{h}	49.70 ± 0.46^{j}	6.45 ± 0.08^{j}	21.34 ± 0.07^{j}
Ficus virens	62.42 ± 0.67^{k}	26.95 ± 0.26^{k}	50.57 ± 0.38^{h}	6.60 ± 0.06^{h}	15.49 ± 0.16^{m}
Prosopis cineraria	64.71 ± 1.21^{i}	30.19 ± 0.47^{j}	54.54 ± 0.42^{e}	7.27 ± 0.07^{e}	21.49 ± 0.30^{i}
Pithecellobium dulce	71.24 ± 0.69^{e}	40.70 ± 0.41^{d}	54.40 ± 0.44^{e}	7.25 ± 0.07^{e}	27.68 ± 0.23^{e}
Moringa oleifera	75.08 ± 0.32^{a}	44.97 ± 1.00^{a}	66.17 ± 0.59^{a}	9.25 ± 0.10^{a}	35.95 ± 0.36^{a}
Morus alba	74.18 ± 0.68^{b}	33.05 ± 0.23^{i}	49.16 ± 0.51^{k}	6.36 ± 0.09^{k}	29.83 ± 0.12^{d}
Azadirachta indica	61.10 ± 1.16^{l}	40.92 ± 0.65^{c}	52.87 ± 0.14^{f}	6.99 ± 0.02^{f}	20.74 ± 0.20^{k}
Salvadora persica	66.02 ± 0.43^{g}	26.19 ± 0.51^{l}	50.18 ± 0.66^{i}	6.53 ± 0.11^{i}	21.97 ± 0.39^{h}
Leucaena leucocephala	70.60 ± 0.25^{f}	36.22 ± 0.54^{f}	58.77 ± 1.11^{b}	7.99 ± 0.19^{b}	32.64 ± 0.38^{b}
T. indica	56.60 ± 0.37^{m}	35.35 ± 0.29^{g}	57.33 ± 0.60^{c}	7.75 ± 0.10^{c}	14.51 ± 0.11^{n}
Mean	67.01	34.22	54.19	7.21	24.19
SEM	1.53	1.90	1.25	0.21	1.69
LSD	0.05	0.07	0.20	0.03	0.09

NFC, non-fibre carbohydrates; TDN, total digestible nutrients; IVTD, *in vitro* true digestibility; ME, metabolizable energy; FNV, forage nutritive value index. Data are given as mean ± SD. SEM, standard error of the mean; LSD, least square difference. The alphabetical letters given as superscript against each value indicates significant differences between tree species at P≤0.05 if letters are different for different tree species, otherwise non-significant if having same letters.

(75.08%), whereas lower (p <0.05) in *T. indica* (56.60%). Non-fiber carbohydrates (NFC) ranged from 23.00 to 44.97%, with a maximum in *M. oleifera* and minimum in *Crescentia cujete*. Higher (p <0.05) *in-vitro* true digestibility (IVTD) and metabolizable energy (ME) were found with the foliage of *M. oleifera* (66.17% and 9.25MJ/kg DM**)**. *M. alba* foliage IVTD is low (49.16%) and had a lower ME value (6.36MJ/kg DM).

Forage nutritive value (FNV) is as high as 36.22 in *L. leucocephala* and as low as 14.51 in *T. indica*. The data concerning the *in-vitro* true digestibility suggest the potential negative impact of fiber, lignin, and tannins, leading to a depressive effect on the foliage of *some tree species* (Ramana *et al*., 2000). As the leaves mature, most of the nutritive components, including CP, total ash, and NFC, along with minerals decrease, whereas cell wall constituents like CF, ADF, and NDF, as well as anti-nutritional factors such as total phenols and tannins increase and this will affect the digestibility, metabolizable energy and forage nutritive value of the foliage from different tree leaves (Navale *et al*., 2022).

Conclusion

The nutrient, anti-nutritional contents and related true digestibility, ME, and FNV of the foliage of the different multipurpose tree species varied significantly. Most of the leafy material from different multipurpose tree species contained (%) medium to high CP and, high degradable DM and moderate NDF. The tannin content in most of the tree leaves was low to medium and may exert a beneficial effect on protein utilization and production attributes in livestock. So, it was concluded that foliage from all the multipurpose tree species has the greatest potential for agroforestry in degraded lands in terms of alternate nutritious fodder supplements for feeding the livestock during the lean period.

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