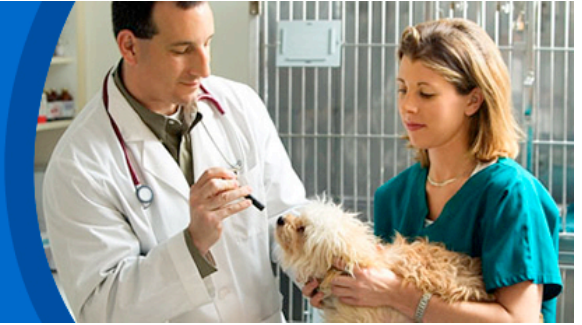




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Comparative proximate composition, Van Soest fiber fractions, and phytochemical profiles of *Moringa oleifera*, *Tamarindus indica*, and *Azadirachta indica* foliage for potential use as ruminant feed resources

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ABSTRACT

Scarcity and high acquisition costs of conventional protein and energy concentrates severely restrict ruminant livestock productivity in arid and semi-arid agro-ecological systems. This investigation presents a comparative biochemical evaluation of mature leaves from three perennial agro-forestry species *Moringa oleifera* Lam., *Tamarindus indica* L., and *Azadirachta indica* A. Juss. harvested under standardized conditions within a single agro-climatic zone. Proximate constituents were determined via standard AOAC protocols, fiber fractions were quantified through sequential Van Soest detergent analysis, and major secondary *anti*-nutritional compounds (total phenols, condensed tannins, and phytate phosphorus) were characterized spectrophotometrically. Data were evaluated using a one-way analysis of variance (ANOVA) in a Completely Randomized Design ($n = 5$). *Moringa oleifera* foliage demonstrated superior nutritional density, exhibiting marked crude protein content ($26.84 \pm 0.42\%$ DM) and lower neutral detergent fiber ($28.31 \pm 0.65\%$ DM) and acid detergent lignin ($5.12 \pm 0.18\%$ DM) compared to *T. indica* and *A. indica* ($P < 0.001$). Conversely, *Tamarindus indica* foliage exhibited substantial cell-wall structural carbohydrates (NDF: $46.22 \pm 0.81\%$; ADF: $31.40 \pm 0.54\%$) alongside the highest condensed tannin concentrations (24.36 ± 0.72 g leucocyanidin equivalent/kg DM). *Azadirachta indica* presented moderate crude protein ($16.45 \pm 0.38\%$ DM) and fiber fractions, coupled with substantial total phenolics (41.15 ± 0.94 g GAE/kg DM). The empirical findings indicate that *M. oleifera* serves as a high-potency concentrate replacer, *T. indica* represents an effective source of fermentable fiber requiring tannin management, and *A. indica* offers functional potential as a bioactive phytochemical supplement when maintained within dietary palatability thresholds.

Keywords: Anti-nutritional factors, Crude protein, Cell-wall lignification, Detergent fiber analysis, Nitrogen-free extract, Tree browse foliage

Introduction

Ruminant production systems throughout tropical and subtropical drylands operate under chronic nutritional stress caused by marked seasonal fluctuations in green biomass and escalating economic constraints surrounding conventional protein feeds (such as soybean meal and groundnut cake) and cereal grains (Makkar, 2018) [1]. Pastoralists and mixed crop-livestock smallholders frequently depend on mature cereal straws and stover as basal diets during extended dry spells. These crop residues are universally characterized by low crude protein (CP < 70g/kg dry matter [DM]), high cell-wall lignification, and poor trace mineral bioavailability, which suppress ruminal cellulolytic fermentation kinetics and depress voluntary dry matter intake (Van Soest, 1994; Leng, 1990) [3, 2].

Perennial deep-rooted fodder trees and shrubs represent strategic feed assets capable of addressing this nutritional deficit. Due to extensive root architectures, these species maintain metabolic vigor, leafy canopy cover, and nutritional synthesis during severe drought conditions, retaining substantial concentrations of nitrogen, minerals, and soluble carbohydrates when herbaceous pastures senesce (Patra, 2010; Devendra *et al.*, 1995) [5, 4]. Among tropical arboreal foliages, *Moringa oleifera* Lam. (Moringaceae), *Tamarindus indica* L. (Fabaceae), and *Azadirachta indica* A. Juss. (Meliaceae) are widely naturalized, agronomic candidates with substantial biomass yields.

Despite their common classification as multi-purpose fodder trees, their biochemical profiles and physiological integration into rumen metabolic pathways diverge significantly:

***Moringa oleifera* (Drumstick tree):** Displays rapid vegetative regeneration and exceptional crude protein content (220 – 290g/kg DM), with an amino acid profile closely aligning with high-grade oilcakes (Makkar

et al., 1996; Moyo *et al.*, 2011) [6, 7]. Its structural cell-wall carbohydrates are minimally lignified, promoting high ruminal organic matter degradability and post-ruminal nitrogen availability (Sultana *et al.*, 2015) [8].

***Tamarindus indica* (Tamarind tree):** A drought-hardy leguminous species yielding moderate nitrogen foliage (120 – 160g/kg DM) coupled with substantial structural fiber. While useful as a roughage supplement, its vegetative matter contains varying amounts of polyphenols, tartaric acid, and condensed tannins that alter microbial protein degradation and gut passage rates (El-Siddig *et al.*, 2006; Dey *et al.*, 2008) [9].

***Azadirachta indica* (Neem tree):** Yields foliage with moderate crude protein (130 – 180g/kg DM) and significant quantities of bioactive secondary triterpenoids, notably azadirachtin, salannin, and nimbidin (Ur-Rehman *et al.*, 2023) [10]. Although these metabolites exert antimicrobial, anthelmintic, and defaunating activities that mitigate enteric methanogenesis, elevated concentrations impart marked bitterness, depressing voluntary intake and cellulolytic enzyme activity (Patra and Saxena, 2010; Garg, 2001) [11].

A significant limitation in applied ruminant nutrition is the lack of standardized, concurrent comparative evaluations of these three foliages harvested from identical agro-climatic boundaries. Previous reports present analytical disparities stemming from variable stages of maturity, disparate post-harvest processing regimes (sun versus shade drying), and uncoordinated analytical frameworks where proximate composition is reported without the necessary context of Van Soest detergent partitioning or quantified *anti*-nutritional profiles.

To resolve these analytical gaps, this investigation tests the following research hypotheses:

- **Hypothesis 1 (H_1):** *Moringa oleifera* foliage contains significantly higher CP and significantly lower acid detergent fiber (ADF) and acid detergent lignin (ADL) compared to *T. indica* and *A. indica*.
- **Hypothesis 2 (H_2):** Anti-nutritional constituents (condensed tannins and total phenolics) are concentrated significantly higher in *T. indica* and *A. indica*, establishing biochemical constraints on dietary inclusion levels.

The specific objectives are: (1) to systematically quantify proximate composition across the three species using AOAC methods; (2) to delineate structural fiber fractions into neutral detergent fiber (NDF), ADF, and ADL using the Van Soest method; and (3) to measure major secondary compounds (total phenolics, condensed tannins, and phytylates) to establish evidence-based feeding recommendations for ruminant diets.

Organic Matter (OM): Derived as:

$$OM (\% \text{ of DM}) = 100 - \text{Ash} (\% \text{ of DM})$$

Detergent fiber fractionation

Cell wall matrix constituents were determined sequentially using the filter bag technique in an ANKOM²⁰⁰ Fiber Analyzer (ANKOM Technology, Macedon, NY) following Van Soest *et al.* (1991) [13]:

Neutral Detergent Fiber (NDF): Digested with neutral detergent solution containing sodium dodecyl sulfate, disodium EDTA, and sodium borate, supplemented with heat-stable α -amylase (Sigma-Aldrich, A3306) to digest starch and sodium sulfite (Na_2SO_3) to remove proteinaceous contaminants. Results are expressed inclusive of residual ash (NDF).

Materials and Methods

Study site and sample collection

Foliage was harvested from mature, healthy trees established within the semi-arid tropical zone of Western India (20°30'N, 74°32'E, elevation 435m above sea level). Five representative, non-adjacent trees per species ($n = 5$ biological replicates) of uniform maturity and crown development were selected. Fully expanded, disease-free compound leaves were excised manually during the pre-flowering vegetative stage during early morning hours to minimize physiological transpirational stress.

Sample processing

Harvested leaves were sorted to exclude non-edible petioles and woody twigs ($> 3\text{mm}$ diameter), gently rinsed with distilled water to remove superficial dust and debris, and blotted dry. To preserve heat-sensitive bioactive constituents and avoid non-enzymatic Maillard browning, samples were shade-dried on perforated stainless steel benches at ambient temperatures (26 – 32°C) with active cross-ventilation until a constant weight was attained. The dried matrices were ground in a laboratory Wiley mill (Model 4, Thomas Scientific, Swedesboro, NJ) fitted with a 1.0mm stainless steel delivery screen, homogenized, and stored in airtight, dark high-density polyethylene (HDPE) containers at 4°C pending chemical analysis.

Proximate chemical analysis

Analyses were executed in analytical triplicates according to standard procedures (AOAC, 2016) [12]:

Dry Matter (DM): Analytical method 934.01; desiccated in a forced-draft convective oven at $105 \pm 2^\circ\text{C}$ for 16h to constant mass.

Crude Protein (CP): Analytical method 2001.11; total nitrogen (N) quantified via automated micro-Kjeldahl digestion and distillation (Kjeltec 8400, FOSS Analytical, Hillerød, Denmark), utilizing a commercial catalyst mixture (K_2SO_4 : CuSO_4 , 9:1w/w) and concentrated H_2SO_4 . Crude protein was derived as:

$$CP (\% \text{ of DM}) = N (\% \text{ of DM}) \times 6.25$$

Ether Extract (EE): Analytical method 920.39; determined by exhaustive extraction using petroleum ether (boiling point 40 – 60°C) in an automated Soxhlet apparatus (Soxtec 2050, FOSS Analytical) for 6h.

Crude Fiber (CF): Analytical method 978.10; sequential digestion of fat-extracted residue with 1.25% (w/v) H_2SO_4 and 1.25% (w/v) NaOH solutions in a Fibertec 2010 hot extraction system, followed by ash ignition at 550°C.

Total Ash: Analytical method 942.05; complete combustion in a programmable muffle furnace at $550 \pm 10^\circ\text{C}$ for 4h.

Nitrogen-Free Extract (NFE): Quantified mathematically by difference on a dry-matter basis:

$$NFE (\% \text{ of DM}) = 100 - [CP + EE + CF + \text{Ash}]$$

Acid Detergent Fiber (ADF): Digested in acid detergent solution containing cetyltrimethylammonium bromide (CTAB) dissolved in 0.5M H_2SO_4 .

Acid Detergent Lignin (ADL): Determined by solubilizing cellulose from the ADF residue via ambient immersion in 72% (w/w) H_2SO_4 for 3h, followed by extensive washing, drying, and subsequent incineration in a muffle furnace at 525°C for 3h.

Cellulose and Hemicellulose: Calculated stoichiometrically:

$$\text{Hemicellulose} = \text{NDF} - \text{ADF}$$

$$\text{Cellulose} = \text{ADF} - \text{ADL}$$

Quantification of anti-nutritional compounds

Total Phenolics (TP): Extracted using aqueous methanol (70% v/v) via ultrasonic assistance at 40°C for 30min. Soluble phenolics were quantified spectrophotometrically using the Folin-Ciocalteu reagent (Makkar, 2003) at $\lambda = 725\text{nm}$. Concentrations were interpolated against a gallic acid standard calibration curve ($R^2 > 0.998$) and reported as grams gallic acid equivalents per kilogram DM (g GAE/kg DM).

Condensed Tannins (CT): Quantified using the butanol-HCl- Fe^{3+} assay (Porter *et al.*, 1986). The red anthocyanidin pigment formed after heating was evaluated at $\lambda = 550\text{nm}$, with final concentrations expressed as grams leucocyanidin equivalent per kilogram DM (g LE/kg DM).

Phytate: Extracted with 2.4% (v/v) HCl and quantified colorimetrically using the Wade reagent (0.03% $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ + 0.3% sulfosalicylic acid) at $\lambda = 500\text{nm}$ against a phytic acid sodium salt calibration curve (Vaintraub *et al.*, 1988) [14].

Statistical analysis

The experiment was structured as a single-factor Completely Randomized Design (CRD). The experimental unit was defined as an individual tree sample ($n = 5$ independent biological replicates per

species). Data were assessed for normal distribution via the Shapiro-Wilk test and homogeneity of variance using Levene's test. Analysis of variance (ANOVA) was executed using the General Linear Model (GLM) procedure in SAS (Version 9.4, SAS Institute Inc., Cary, NC):

$$Y_{ij} = \mu + T_i + \varepsilon_{ij}$$

Where Y_{ij} is the dependent variable, μ is the overall population mean, T_i is the fixed effect of the foliage species ($i = 1, 2, 3$), and ε_{ij} is the random residual error term $\sim N(0, \sigma^2)$. Significant differences among treatment means were separated using Tukey's Honestly Significant Difference (HSD) post-hoc test. Threshold significance was established at $\alpha = 0.05$.

Results

Proximate chemical composition

The proximate composition of *M. oleifera*, *T. indica*, and *A. indica* dried leaf foliage is summarized in Table 1.

Table 1. Proximate chemical composition of *Moringa oleifera*, *Tamarindus indica*, and *Azadirachta indica* foliage (% DM basis, $n = 5$)

Parameter	<i>M. oleifera</i>	<i>T. indica</i>	<i>A. indica</i>	SEM	P-value
Dry Matter (DM, %)	91.82 ^b	90.74 ^b	93.15 ^a	0.34	0.002
Organic Matter (OM)	90.18 ^a	92.86 ^a	88.75 ^b	0.41	< 0.001
Crude Protein (CP)	26.84 ^a	14.22 ^c	16.45 ^b	0.42	< 0.001
Ether Extract (EE)	6.82 ^a	3.85 ^c	4.92 ^b	0.21	< 0.001
Crude Fiber (CF)	9.15 ^c	21.30 ^a	14.80 ^b	0.46	< 0.001
Total Ash	9.82 ^b	7.14 ^c	11.25 ^a	0.28	< 0.001
Nitrogen-Free Extract (NFE)	47.37 ^c	53.49 ^a	52.58 ^b	0.52	< 0.001

Note: Means within a row bearing different superscript lowercase letters (^{a, b, c}) differ significantly ($P < 0.05$). SEM = Standard Error of the Mean.

Moringa oleifera exhibited a significantly higher crude protein concentration (26.84%) than both *A. indica* (16.45%) and *T. indica* (14.22%) ($P < 0.001$). Ether extract content followed an identical trend, with *M. oleifera* yielding 6.82%, surpassing *A. indica* (4.92%) and *T. indica* (3.85%). In contrast, crude fiber was lowest in *M. oleifera* (9.15%) and reached its maximum in *T. indica* (21.30%). Total

ash was highest in *A. indica* (11.25%, $P < 0.001$), indicating elevated mineral loading, while *T. indica* exhibited the lowest total inorganic fraction (7.14%).

Cell-wall fiber partitioning (Van Soest system)

The distribution of structural carbohydrates across the species is delineated in Table 2.

Table 2. Van Soest cell-wall fiber fractions of *Moringa oleifera*, *Tamarindus indica*, and *Azadirachta indica* foliage (% DM basis, $n = 5$)

Fiber Fraction	<i>M. oleifera</i>	<i>T. indica</i>	<i>A. indica</i>	SEM	P-value
Neutral Detergent Fiber (NDF)	28.31 ^c	46.22 ^a	38.90 ^b	0.65	< 0.001
Acid Detergent Fiber (ADF)	17.45 ^c	31.40 ^a	24.75 ^b	0.54	< 0.001
Acid Detergent Lignin (ADL)	5.12 ^c	9.85 ^a	7.60 ^b	0.18	< 0.001

(continued on next page)

Fiber Fraction	<i>M. oleifera</i>	<i>T. indica</i>	<i>A. indica</i>	SEM	P-value
Hemicellulose	10.86 ^c	14.82 ^a	14.15 ^a	0.35	< 0.001
Cellulose	12.33 ^c	21.55 ^a	17.15 ^b	0.44	< 0.001

Note: Means within a row bearing different superscript lowercase letters (^{a, b, c}) differ significantly ($P < 0.05$). Hemicellulose calculated as (NDF – ADF); Cellulose calculated as (ADF – ADL).

Moringa oleifera possessed the lowest structural fiber profile ($P < 0.001$), with NDF at 28.31%, ADF at 17.45%, and ADL at 5.12%. Conversely, *T. indica* had the highest cell-wall concentrations, with NDF (46.22%) and ADF (31.40%) exceeding those of *A. indica* and *M. oleifera*. The lignification index, reflected by ADL, followed the descending order: *T. indica* (9.85%) > *A. indica* (7.60%) > *M. oleifera*

(5.12%). Hemicellulose content was comparable between *T. indica* (14.82%) and *A. indica* (14.15%), but was significantly lower in *M. oleifera* (10.86%).

Anti-nutritional and phytochemical profiles

Phytochemical quantification of anti-nutritional constituents indicated pronounced species-dependent divergence (Table 3).

Table 3. Anti-nutritional factors and secondary metabolites of *Moringa oleifera*, *Tamarindus indica*, and *Azadirachta indica* foliage (DM basis, $n = 5$)

Phytochemical Constituent	<i>M. oleifera</i>	<i>T. indica</i>	<i>A. indica</i>	SEM	P-value
Total Phenols (g GAE/kg)	18.42 ^c	32.18 ^b	41.15 ^a	0.94	< 0.001
Condensed Tannins (g LE/kg)	3.25 ^c	24.36 ^a	8.82 ^b	0.72	< 0.001
Phytate (g/kg)	14.12 ^a	6.45 ^c	8.90 ^b	0.38	< 0.001

Note: Means within a row bearing different superscript lowercase letters (^{a, b, c}) differ significantly ($P < 0.05$). GAE = Gallic Acid Equivalents; LE = Leucocyanidin Equivalents.

Total phenolics were highest in *A. indica* (41.15g GAE/kg), significantly exceeding *T. indica* (32.18g GAE/kg) and *M. oleifera* (18.42g GAE/kg). In contrast, condensed tannins were concentrated in *T. indica* (24.36g LE/kg), showing a 7.5-fold increase over *M. oleifera* (3.25g LE/kg). Phytate concentration displayed an inverse trend: *M. oleifera* contained the highest concentration (14.12g/kg), which was significantly greater than *A. indica* (8.90g/kg) and *T. indica* (6.45g/kg) ($P < 0.001$).

Discussion

Comparative protein matrix and nitrogen value

Crude protein is the primary limiting nutrient for ruminants fed low-quality tropical basal diets. Rumen cellulolytic microorganisms require a minimum dietary threshold of 70g CP/kg DM (7.0%) to maintain basic hydrolytic activity on structural polysaccharides; levels below this suppress voluntary intake through ruminal impaction (Van Soest, 1994) [3]. All three tested foliages exceeded this threshold, confirming their viability as supplemental protein sources.

Moringa oleifera foliage exhibited marked protein accumulation (26.84%), confirming its role as a concentrated nitrogen source capable of substituting for conventional oilseed meals such as soybean meal or mustard cake (Sánchez et al., 2006; Moyo et al., 2011) [15, 7]. The elevated ether extract fraction in *M. oleifera* (6.82%)—primarily composed of unsaturated fatty acids, including α -linolenic acid (Makkar et al., 1996) [6]—supplies readily available gross energy without exceeding the 6 – 7% dietary lipid limit that impairs ruminal fiber digestion. While *T. indica* (14.22%) and *A. indica* (16.45%) yielded lower crude protein compared to *Moringa*, both provide sufficient nitrogen to function as maintenance or moderate production supplements for small ruminants consuming poor-quality roughages.

Cell-wall lignification and digestive mechanics

The voluntary intake and ruminal degradability of forages are largely governed by their NDF and ADF concentrations, which dictate rumen fill, chewing time, and gut clearance rates (Van Soest et al., 1991) [13]. The NDF fraction of *M. oleifera* (28.31%) was significantly

lower than the 50 – 60% threshold typically associated with voluntary intake depression in tropical ruminants. Coupled with its modest ADF (17.45%) and ADL (5.12%), *Moringa* provides low physical resistance to microbial enzymatic breakdown, correlating with elevated *in vitro* dry matter digestibility reported in previous studies (Soliva et al., 2005) [16].

In contrast, *T. indica* exhibited significant cell-wall development (46.22% NDF, 31.40% ADF), accompanied by higher core lignification (9.85% ADL). Because lignin is physically linked to hemicellulose via covalent ferulate cross-links, elevated ADL concentrations present a physical barrier that restricts bacterial cellulolytic access to structural polysaccharides. Consequently, while *T. indica* supplies functional structural fiber for rumination, its total organic matter digestibility is predictably lower than that of *Moringa*, suggesting its utility is best suited as a partial roughage replacer. *Azadirachta indica* occupied an intermediate position, presenting balanced fiber partitioning that supports ruminal function without inducing excessive physical fill.

Bioactive secondary metabolites and physiological thresholds

Anti-nutritional factors represent evolutionary chemical defense mechanisms against herbivory, yet their physiological impact on ruminants varies based on chemical structure and ingestion rate.

The condensed tannin (proanthocyanidin) concentration observed in *T. indica* (24.36g/kg DM) falls within the biologically active range of 20 – 40g/kg DM. In this range, condensed tannins form stable, pH-dependent hydrogen-bonded complexes with dietary proteins within the near-neutral ruminal environment (pH 6.0 – 6.8), shielding them from microbial deamination and proteolysis (Patra et al., 2010) [11]. These complexes dissociate in the acidic abomasum (pH < 3.0), releasing free amino acids for absorption in the duodenum, which enhances nitrogen utilization efficiency and mitigates urinary nitrogen excretion (Min et al., 2003) [17]. However, if *Tamarindus* foliage is fed in excess, condensed tannins can bind directly to microbial cell walls and extracellular cellulases, impairing structural carbohydrate digestion.

Azadirachta indica accumulated high concentrations of total phenolics (41.15g GAE/kg DM), coupled with its characteristic bitter limonoids (triterpenoids such as azadirachtin and nimbidin) (Ur-Rehman *et al.*, 2023) [10]. While these secondary compounds possess broad-spectrum anthelmintic and protozoal-defaunating capabilities—reducing enteric methanogenesis by suppressing associated methanogenic archaea (Dey *et al.*, 2008)—their bitterness presents a palatability barrier. Unadapted livestock often reject unblended neem foliage, suggesting dietary inclusion should be limited to 10 – 15% in complete feed formulations or balanced via gradual adaptation (Garg, 2001).

The elevated phytate concentration in *M. oleifera* (14.12g/kg DM) is of minor consequence in mature ruminants. Unlike monogastric species, the resident ruminal microflora synthesizes endogenous phytase enzymes capable of hydrolyzing the *myo*-inositol hexakisphosphate ring, releasing bioavailable inorganic orthophosphate and chelated divalent cations (Ca^{2+} , Mg^{2+} , Zn^{2+}) for systemic absorption (Yanke *et al.*, 1998) [18].

Synthesis and dietary strategic allocation

Synthesizing these nutritional parameters suggests distinct feed allocation strategies across the evaluated foliages:

Moringa oleifera is an exceptional protein and energy resource that can be utilized as a direct substitute for high-cost commercial concentrates in high-producing lactating or rapidly growing livestock.

Tamarindus indica supplies fermentable fiber and condensed tannins, making it suitable as an intermediate roughage supplement that reduces ruminal protein degradation when fed alongside highly soluble nitrogen sources.

Azadirachta indica functions as a secondary phytogenic feed additive that provides baseline crude protein while contributing bioactive metabolites useful for internal parasite control and rumen fermentation modulation, provided dietary inclusion is managed to protect feed intake.

Conclusion

This comparative analysis demonstrates significant differences in proximate composition, structural fiber architecture, and secondary anti-nutritional profiles among *Moringa oleifera*, *Tamarindus indica*, and *Azadirachta indica* foliage:

Moringa oleifera exhibits superior nutritional properties, characterized by high crude protein (26.84%), elevated ether extract (6.82%), and minimal core lignification (5.12%), making it a viable substitute for traditional vegetable protein meals.

Tamarindus indica foliage is rich in structural cell-wall carbohydrates (46.22% NDF) and condensed tannins (24.36g/kg), serving as a moderate-energy forage that promotes protein bypass mechanisms when fed in balanced proportions.

Azadirachta indica provides balanced crude protein (16.45%) alongside high phenolic concentrations (41.15g/kg), indicating significant functional value as a dietary supplement for microbial modulation, provided palatability limits are observed.

Integrating these alternative tree foliages into ruminant feeding regimens offers smallholders an evidence-based approach to mitigate dry-season feed deficits, lower reliance on commercial concentrates, and enhance the environmental sustainability of tropical livestock operations.

References

- Makkar HS. Feed demand landscape and implications of food-not feed strategy for food security and climate change. *Animal*. 2018;12(8):1744-1754.
- Leng RA. Factors affecting the utilization of 'poor-quality' forages by ruminants particularly under tropical conditions. *Nutrition research reviews*. 1990;3(1):277-303.
- Van Soest PJ. Nutritional ecology of the ruminant. Cornell university press; 1994.
- Devendra C, D'Mello JPF, Devendra C. Composition and nutritive value of browse legumes. *Tropical legumes in animal nutrition*. Wallingford: CAB INTERNATIONAL; 1995:49-65.
- Patra AK. Meta-analyses of effects of phytochemicals on digestibility and rumen fermentation characteristics associated with methanogenesis. *Journal of the Science of Food and Agriculture*. 2010;90(15):2700-2708.
- Makkar HPS, Becker K. Nutritional value and antinutritional components of whole and ethanol extracted *Moringa oleifera* leaves. *Animal Feed Science and Technology*. 1996;63(1-4):211-228.
- Moyo B, Masika PJ, Hugo A, Muchenje V. Nutritional characterization of *Moringa (Moringa oleifera Lam.)* leaves. *African journal of biotechnology*. 2011;10(60):12925-12933.
- Sultana N, Alimon AR, Huque KS, Sazili AQ, Yaakub H, Hossain J, Baba M. The feeding value of *Moringa (Moringa oleifera)* foliage as replacement to conventional concentrate diet in Bengal goats. *Adv. Anim. Vet. Sci*. 2015;3(3):164-173.
- El-Siddig K, Gunasena HPM, Prasad BA, Pushpakumara DKN, Ramana KVR, Vijayanand P, Williams JT. *Tamarind: Tamarindus indica L. Crops for the Future*, Southampton, UK; 2006.
- Ur-Rehman T, El-Mansi AA, Alhag SK, Al-Shuraym LA, Saeed Z, Arif M, Zaman MA. Antiparasitic Activity of Methanolic and Ethyl acetate Extracts of *Azadirachta indica* against *Haemonchus contortus*. 2023.
- Patra AK, Saxena J. A new perspective on the use of plant secondary metabolites to inhibit methanogenesis in the rumen. *Phytochemistry*. 2010;71(11-12):1198-1222.
- AOAC Official Methods Committee. Official methods of analysis of AOAC international. Association of Official Analytical Chemists; 2016.
- Van Soest PV, Robertson JB, Lewis BA. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of dairy science*. 1991;74(10):3583-3597.
- Vaintraub IA, Lapteva NA. Colorimetric determination of phytate in unpurified extracts of seeds and the products of their processing. *Analytical biochemistry*. 1988;175(1):227-230.
- Sánchez NR, Ledin S, Ledin I. Biomass production and chemical composition of *Moringa oleifera* under different management regimes in Nicaragua. *Agroforestry Systems*. 2006;66(3):231-242.
- Soliva CR, Kreuzer M, Foidl N, Fievez V, Hess HD. Feeding value of whole and extracted *Moringa oleifera* leaves for ruminants and their effects on ruminal fermentation in vitro. *Animal Feed Science and Technology*. 2005;118(1-2):47-62.
- Min BR, Barry TN, Attwood GT, McNabb WC. The effect of condensed tannins on the nutrition and health of ruminants fed fresh temperate forages: a review. *Animal feed science and technology*. 2003;106(1-4):3-19.
- Yanke LJ, Bae HD, Selinger LB, Cheng KJ. Phytase activity of anaerobic ruminal bacteria. *Microbiology*. 1998;144(6):1565-1573.
- Bhosale T, Chavan MK, Sabale T, Lavar V. Proximate analysis of *Azadirachta indica* & *Moringa oleifera* L. leaves as feed additives for ruminants. *Pharm J Innova SP*. 2021;10:1886.
- Aruwayo A, Maigandi SA. Neem (*Azadirachta indica*) seed cake/kernel as protein source in ruminants feed. 2013.
- Makkar HP. Quantification of tannins in tree and shrub foliage: a laboratory manual. Springer Science & Business Media; 2013.

22. Porter LJ, Hrstich LN, Chan BG. The conversion of procyanidins and prodelphinidins to cyanidin and delphinidin. *Phytochemistry*. 1985;25(1):223-230.

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