Research Article

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Nutritional, Phytochemical and *In-vitro* Fermentation Characteristics of Pelleted Concentrate Feed Containing Moringa *(Moringa oleifera)* and Hedge lucerne *(Desmanthus virgatus)* Leaves on Camel *(Camelus dromedarius)* Calves

Edited by: Pradeep Kumar Malik
National Institute of Animal Nutrition and Physiology, Bengaluru, Karnataka

Reviewed by: N Ramachandran
National Institute of Animal Nutrition and Physiology
Bengaluru, Karnataka

*Correspondence: Pallabi Das
pallabidas066@gmail.com

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Pallabi Das[1]*, Rajesh Kumar Dhuria[1] and Rajesh Kumar Sawal[2]

[1]*Department of Animal Nutrition, CVAS, Bikaner, India-334001*
[2]*ICAR-National Research Centre on Camel, Bikaner, India-334001*
**corresponding author: pallabidas066@gmail.com*

This study investigated the potential of tree leaves as alternative feed resource by evaluating their nutritional composition, nitrogen fractions, phytochemical constituents, antioxidant activity and *in-vitro* fermentation characteristics of pelleted concentrate feeds containing Moringa and Hedge lucerne leaves. Three iso-nitrogenous pelleted diets were formulated: a control diet based on conventional roughages (T_1), diets containing 10% Moringa leaf incorporated pelleted meal (T_2) and 10% Hedge lucerne leaf incorporated pelleted meal (T_3). Samples were analyzed for proximate composition, fibre fractions, Neutral Detergent Insoluble Nitrogen (NDIN), Acid Detergent Insoluble Nitrogen (ADIN), polyphenolic fractions, saponins, and antioxidant activity. *In-vitro* gas production, methane emission, Metabolizable Energy (ME), Net Energy (NE) and short-chain fatty acid production were analyzed. Both Moringa and Hedge Lucerne leaf incorporated concentrated pelleted sources exhibited high crude protein content (25.06-26.30%) with favourable nitrogen fractions. Incorporation of tree leaves significantly enhanced total polyphenols, non-tannin polyphenols, flavonoids and saponins in pelleted feeds. The condensed tannins and other anti-nutritional factors were within safe limits. Moringa leaves showed higher total antioxidant capacity, hydroxyl and superoxide radical scavenging, and metal chelating activities, whereas Hedge lucerne leaves exhibited slightly higher 2,2-diphenyn-1-picrylhydrazyl (DPPH) radical scavenging activity. *In-vitro* total gas production, methane emission, ME, NE and Short Chain Fatty Acid (SCFA) concentrations were non-significant in all the treatments, although improvements in energy values and reduced methane in T_2 were observed. Overall, incorporation of Moringa and Hedge lucerne leaves at 10% in pelleted concentrate feeds improved protein quality, phyto-chemical enrichment and antioxidant potential which were sustainable and cost-effective alternative in livestock feeding.

Keywords: Phytochemicals; Antioxidant activity; Pelleted concentrate feed; Tree leaves

Introduction

The increasing cost and limited availability of conventional concentrate feed ingredients such as oilseed cakes and cereal grains pose major challenges to sustainable livestock production, particularly in developing countries where feed accounts for a major portion of total production cost (FAO, 2020; Smith and Jones, 2021). This has stimulated interest in exploring alternative, locally available and nutrient-rich feed resources (Makkar, 2022). Tree leaves and leguminous forages are promising options due to their high crude protein content, favourable nitrogen fractions and presence of bioactive compounds (Patra and Saxena, 2021). *Moringa oleifera* and *Desmanthus virgatus* leaves are known for their superior protein quality with moderate NDIN and low ADIN, which enhance ruminal degradability and protein utilization (Leitanthem *et al*., 2023). Additionally, these leaves contain phytochemicals such as polyphenols, tannins, flavonoids and saponins that improve rumen fermentation, reduce methane emission and enhance animal health (Jayanegara *et al*., 2022; Patra and Yu, 2021). Their antioxidant properties further contribute to reducing oxidative stress and improving metabolic efficiency (Abu El-Hamd *et al*., 2025). Pelleting improves feed handling, intake consistency and stability of bioactive compounds (Thomas *et al*., 2020). So, it will help the commercial feed industry to adopt these feeds and produce affordable, balanced, and health-supporting diets for livestock. Therefore, the present research was designed to evaluate and compare the nutritional composition, nitrogen fractions, phytochemical content and antioxidant activities of pelleted concentrate feeds containing Moringa and Hedge lucerne leaves on *in-vitro* total gas production and energy values. This work aims to provide scientific evidence supporting the use of leaves as sustainable, cost-effective alternatives in livestock feeding strategies.

Materials and Methods

The study was conducted at ICAR-National Research Centre on Camel (NRCC), located in the Jorbeer area of Bikaner city, Rajasthan, India. The Centre is situated at 28°01′ N latitude and 73°11′ E longitude, with a time zone of GMT +05:30 h. Ambient temperatures generally range from 30 to 48 °C during summer and from 4 to 28 °C during winter.

The protocol of experiment was sanctioned by Institutional Animal Ethical Committee (IAEC) at ICAR-NRCC/IAEC/2024/19/01. Animals were cared and managed as per protocol and directives of IAEC.

Three iso-nitrogenous pelleted concentrate feeds were formulated on a dry matter basis using conventional roughages (T_1), 10% *Moringa oleifera* leaf meal (T_2), and 10% Hedge lucerne (*Desmanthus virgatus*) leaf meal (T_3). The roughage component consisted of groundnut straw (*Arachis hypogaea*) and guar straw (*Cyamopsis tetragonoloba*) mixed in a 50:50 ratio. The concentrate mixture comprised groundnut cake, til cake, mustard cake, cottonseed cake, maize, moong churi, and bajra grains. Molasses was used as a binding agent during pelleting. The nutrient requirements of the experimental animals were formulated to meet ICAR (2013) standards. Fifteen healthy un-weaned female camel calves of similar age (3-4 months), body weight, and uniform conformation were randomly selected from the camel herd of ICAR-NRCC, Bikaner. The calves were randomly allotted to three

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treatment groups (n = 5 per group) for a feeding trial of 180 days. The experimental camel calves were allocated to three treatment groups (T_1, T_2, and T_3) following a randomized block design, with five calves in each group. Calves in the control group (T_1) were fed a pelleted concentrate without leaf inclusion, whereas calves in treatment groups T_2 and T_3 received pelleted concentrate mixtures containing 10% Moringa leaves and 10% Hedge lucerne leaves, respectively. All animals were fed individually throughout the experimental period.

Leaves of Moringa and Hedge lucerne were collected from the NRCC campus, air-dried, and ground into powder form. The leaf meals were incorporated with the concentrate mixture and processed into pellets using a pelleting machine. The dried feed samples were analyzed for dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), and crude fiber (CF) following AOAC (2016) procedures. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were determined according to Van Soest *et al*. (1991).

Total polyphenols and polyphenol fractions were analyzed by the methods described by Hagerman *et al*. (2000). Determination of total phenols, total tannins and condensed tannins in the samples were carried out by following the procedure described by Makkar (2003). Total phenols and total tannins were assessed by a modified Folin Ciocalteu method using polyvinyl polypyrrolidone for separating non-tannin phenols from tannin phenols. Condensed tannins were analysed by the butanol-HCl-iron method (Porter *et al*., 1986). Hydrolysable tannins were estimated as the difference between total tannins and condensed tannins. Total phenols and total tannins were expressed as tannic acid equivalents, while CT as leucocyanidin equivalents. Total saponin was estimated as per procedure described by Makkar (2007). Total Flavonoids were estimated using $AlCl_3$ method. Oxalates and HCN were estimated by titration method ($KMnO_4$ and $AgNO_3$).

DPPH radical scavenging activity was determined by using DHPP assay according to Chang *et al*. (2001). Phosphomolybdate assay was evaluated by the method of Prieto (1999). Hydroxyl radical scavenging activity was determined according to (Halliwell and Gutteridge, 1981). Superoxide anion radical scavenging activity was evaluated according to Nishikimi *et al*. (1972). Metal chelating activity was performed according to Soler-Rivas *et al*. (2000).

Accurately weighed ground substrates (200 mg) for gas production kinetics were transferred into the syringes, and anaerobic culture medium. Syringes were incubated in an incubator maintained at 39 °C and shaken manually every two hr intervals. The gas production was recorded at 0, 2, 4, 6, 8 and 12 hr of incubation taking the reading from the graduated syringes. Net gas production was calculated by subtracting the volume of gas produced in blank from the volume of gas produced from incubated feeds. Incubations were terminated for total gas, methane production and fermentation variables. Metabolisable energy was determined using gas production and chemical analysis Crude Protein (CP) and Ether Extract (EE) data. All the determinations were carried out by using McDougall buffer and 10 ml SRL as described by Menke *et al*. (1979) in triplicate. Strained rumen liquor was used as inoculum for *in vitro* digestibility and gas production studies. The metabolizable energy (ME) was calculated as per Elghandour *et al*. (2015).

ME (MJ/kg DM) = 2.20+0.136 Gp+0.057 CP%, (R^2=0.94), where, CP is crude protein% and Gp is ml of net gas production from 200 mg dry sample.

The data generated during the experiment was subjected to statistical analysis using SPSS statistical software (2011) Version 20.0 and the data were statistically analyzed using one-way and two-way ANOVA procedures for difference between treatments and periods. The difference between means was declared significant at $P<0.05$ and $P<0.01$. Duncan's multiple range test was conducted for comparing among the averages.

Results and Discussion

The proximate composition and fibre fractions of the leaves and experimental feeds are presented in Table 1. The dry matter and crude protein contents of Moringa leaves were 23.22% and 25.06%, respectively, whereas the corresponding values for Hedge lucerne leaves were 25.03% and 26.30%.

In the present investigation, the total nitrogen content of Moringa and Hedge lucerne leaves was found to be 4.01% and 4.208%, respectively (Table 2). The total nitrogen content of the pelleted concentrate feeds (T_1, T_2, and T_3) was recorded as 4.34%, 4.51%, and 4.64%, respectively. The neutral detergent insoluble nitrogen content of Moringa and Hedge lucerne leaves was 1.21% and 0.90%, respectively. In comparison, the NDIN content of the pelleted concentrate feeds T_1, T_2, and T_3 was 3.46%, 2.64%, and 0.59%, respectively. The acid detergent insoluble nitrogen content recorded in Moringa and Hedge lucerne leaves was 0.38% and 0.43%, respectively. Similarly, ADIN values of 0.13%, 0.32%, and 0.39% were observed in the pelleted concentrate feeds T_1, T_2, and T_3, respectively. The ratio of acid detergent insoluble nitrogen to total nitrogen was observed to be 9.57% in Moringa leaves, 10.31% in Hedge lucerne leaves and 3.13%, 7.19%, and 8.52% in T_1, T_2, and T_3 pelleted concentrate feeds, respectively, as presented in Table 2. The polyphenolic fractions and saponin contents of the roughage sources and pelleted feeds offered to different dietary groups (% on DM basis) are presented in Tables 3 and 4.

Table 1. Chemical composition of experimental pelleted concentrate feeds (% DM basis)

Proximate	Moringa leaves	Hedge lucerne leaves	T_1	T_2	T_3
DM	23.22	25.03	96.76	95.99	96.08
OM	91.31	91.88	95.64	96.67	96.64
CP	25.06	26.30	17.14	18.24	18.02
EE	4.42	3.42	4.19	3.43	4.38
CF	17.35	14.45	9.55	6.70	9.71
NFE	35.77	39.59	50.40	54.96	49.56
TA	17.37	16.22	8.70	6.64	7.31
TCHO	61.81	62.15	66.38	64.99	62.93
NDF	39.53	42.40	26.62	26.56	28.33
ADF	32.24	34.60	15.30	15.34	20.70
Lignin	7.28	9.88	4.39	6.32	5.11
Cellulose	22.40	13.31	17.68	17.82	15.77
Hemicellulose	7.29	7.79	11.32	11.22	7.63

DM=Dry Matter; OM=Organic Matter; CP=Crude Protein; EE=Ether Extract; CF=Crude Fiber; NFE=Nitrogen Free Extract; TA=Total Ash; TCHO=Total Carbohydrate; NDF= Neutral Detergent Fiber; ADF= Acid Detergent Fiber.

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Table 2. Nitrogen fractions of tree leaves and pelleted concentrate feeds

Nitrogen Fractions	Moringa leaves	Hedge Lucerne leaves	T_1	T_2	T_3
Total N (%)	4.01±0.04	4.20 ±0.03	4.34±0.05	4.51±0.00	4.64±0.00
NDIN (%)	1.21±0.00	0.90±0.00	3.46±0.00	2.64±0.00	0.59±0.00
ADIN (%)	0.38±0.00	0.43±0.00	0.13±0.00	0.32±0.00	0.39±0.00
ADIN/TN (%)	9.57±0.12	10.31±0.07	3.13±0.06	7.19±0.03	8.52±0.04

Total N=Total Nitrogen; NDIN=Neutral Detergent Insoluble Nitrogen; ADIN=Acid Detergent Insoluble Nitrogen;

Table 3. Polyphenolic fractions and saponin in roughage sources used in pelleted feeds (% DM basis)

Phytochemicals	Groundnut straw	Guar straw	Moringa leaves	Hedge Lucerne leaves
Total Polyphenols	1.38	0.71	6.36	7.17
Total Tannin Polyphenols	0.96	0.35	1.65	2.79
Non- tannin Polyphenols	0.42	0.36	4.71	4.38
Condensed Tannin	0.33	0.04	1.16	1.02
Hydrolysable Tannin	0.41	0.25	0.92	0.78
Saponin	2.98	2.72	2.11	1.91
Flavonoids	0.33	1.36	1.43	0.38
Oxalate	0.98	1.26	0.31	0.12
Hydrogen cyanide	0.0010	0.0021	0.0003	0.0050

The antioxidant Assay measures the ability of antioxidants to scavenge and neutralize free radicals. Antioxidants help in protecting against oxidative stress and related disease. The antioxidant Assay of Moringa and Hedge lucerne leaves are presented in Table 5 and Fig.1. Hedge lucerne leaves have marginally higher DPPH radical scavenging activity compared to Moringa leaves.

Table 4. Polyphenolic fractions and saponin in pelleted concentrate feeds fed to different dietary groups (% DM basis)

Phytochemicals	T_1	T_2	T_3
Total Polyphenols	2.18±0.01	2.66±0.01	3.24±0.00
Total Tannin Polyphenols	0.90 ±0.00	0.36 ±0.00	0.38 ±0.00
Non- tannin Polyphenols	1.28 ±0.01	2.30 ±0.00	2.86±0.00
Condensed Tannin	0.38 ±0.01	0.31±0.00	0.44±0.00
Hydrolysable Tannin	0.43±0.00	0.22 ±0.00	0.18 ±0.00
Saponin	0.57±0.01	1.98 ±0.00	0.41±0.00
Flavonoids	1.00 ±0.03	2.01±0.00	1.11±0.12
Oxalate	0.02±0.00	0.04±0.00	0.01 ±0.00

Table 5. Antioxidant Assay in Moringa and Hedge Lucerne leaves

Attributes (%)	Moringa leaves	Hedge Lucerne leaves	P value
DPPH radical scavenging activity (% RSA)	80.88^{a}±0.01	83.58^{b} ±0.23	0.001
Phosphomolybdate assay (Total antioxidant capacity)	14.81^{b}±0.00	8.23^{a} ±0.01	0.001
Hydroxyl radical scavenging activity (% HRSA)	13.01^{b}±0.00	8.09^{a} ±0.01	0.001
Superoxide anion radical scavenging activity (SOD)	68.1^{b} ±0.01	46.01^{a} ±0.00	0.001
Metal chelating activity	60.63^{b}±0.01	48.42^{a} ±0.02	0.001

^{ab} Means with different superscripts in a row differ significantly (P<0.01)

The effect of leaves-incorporated pelleted concentrate feed on total gas production, methane emission, metabolizable energy (ME), net energy (NE) and short-chain fatty acids (SCFA) is summarized in Table 6 and Fig.2. No significant differences were observed among treatments for total gas production, methane production, ME, NE, or SCFA concentrations, although numerical variations were evident.

Table 6. Effect of leaves incorporated in pelleted concentrate feed on Total gas production, ME, NE and SCFA

Attributes	T_1	T_2	T_3	P value
Total gas production (ml)	22.88±12.34	28.00±7.15	22.00±4.48	0.306
Ch_4 production(ml)	8.78±1.92	8.08±2.64	7.08±1.98	0.506
ME (Mcal/kg DM)	1.49±0.20	1.68±0.26	1.49±0.21	0.297
NE (Mcal/kg DM)	1.00±0.13	1.12±0.18	1.02±0.13	0.409
SCFA (mM)	0.26±0.07	0.31±0.09	0.24±0.07	0.318

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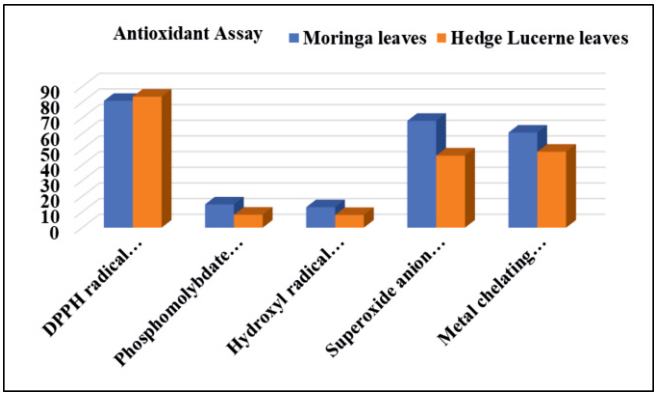

Fig.1. Graph denoting various antioxidant profile present in both the leaves namely Moringa and Hedge lucerne leaves

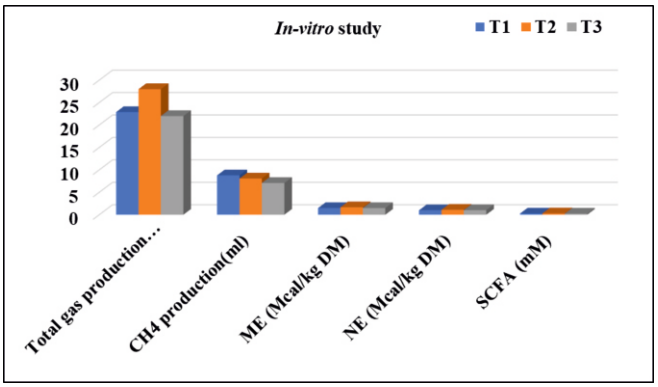

Fig.2. Graph showing total gas production, methane emission, metabolizable energy, net energy and short-chain fatty acids in different treatment groups

The results revealed variations among leaf sources and formulated diets due to differences in nutrient density and fibre fractions relevant to feed utilization and animal performance. Higher DM and OM contents in T_1, T_2, and T_3 indicate improved storage stability and formulation quality. Hedge lucerne (26.30%) and Moringa leaves (25.06%) showed higher CP levels, confirming their value as plant protein sources, whereas formulated diets contained moderate CP (17.14-18.24%), remaining adequate for maintenance and moderate production. EE was highest in T_3 (4.38%) whereas, CF, NDF, ADF and lignin were substantially higher in Hedge lucerne leaves, indicating greater structural carbohydrates. In contrast, reduced fibre fractions and lignin in T_1-T_3 suggest improved digestibility and feed quality. Higher NFE and total carbohydrates in the formulated diets, especially T_2, reflect enhanced availability of soluble carbohydrates for rumen fermentation. Overall, the formulated diets exhibited a more balanced nutrient and fibre profile compared to sole leaf sources, supporting improved digestibility and efficient nutrient utilization. The results of the present study are in agreement with the compiled information reported by Garg *et al*. (2012), Kholif *et al*. (2015), Jayaprakash *et al*. (2016), Thirumeignanam *et al*. (2019), Sonawane *et al*. (2019), Wankhede *et al*. (2022) and Masitlha *et al*. (2024). However, variations in the nutrient composition of leaves have been reported by other researchers, including Suksombat and Buakeeree (2006), Radhakrishanan *et al*. (2007), Hassan *et al*. (2020) and Mynavathi *et al*. (2021). The possible variation in crude protein content is the response of Moringa and Hedge lucerne leaves to environmental conditions, soil nutrients and time of collection which affect chemical composition.

The nitrogen fractionation revealed marked differences among Moringa leaves, Hedge lucerne leaves and pelleted concentrate feeds. Total nitrogen content was highest in Hedge lucerne leaves and increased progressively in pelleted feeds containing tree leaves, revealed improved crude protein supply. The lower ADIN and ADIN/total N ratio observed in Moringa leaves and T_2 diet denotes superior protein availability, as ADIN represents heat-damaged or indigestible protein fractions. Diets with lower ADIN values are associated with enhanced ruminal degradability and intestinal protein absorption. A higher NDIN value in Hedge lucerne leaves reflect a greater proportion of rumen slowly degradable protein, which can sustain microbial growth over time. Pelleting reduce NDIN content in concentrate feeds, likely due to structural disruption of cell walls therefore improving nitrogen accessibility. Therefore, it indicates incorporation of tree leaves improved protein quality without increasing indigestible nitrogen fractions. The nitrogen fractions of leaves have been reported by other researchers, including Bhatt *et al*. (2020).

Tree leaves exhibited higher concentrations of total polyphenols, tannins and flavonoids compared to conventional roughages. Hedge lucerne leaves showed the highest total polyphenols, while Moringa leaves contained greater non-tannin polyphenols and flavonoids. These compounds are known to have antioxidant, antimicrobial and rumen-modulatory effects. Total polyphenols and non-tannin polyphenols increased in T_2 and T_3 diets showing their antioxidant potential. These compounds are known to modulate rumen microbial populations, suppress oxidative stress and improve animal health. Saponin content was comparatively higher in groundnut and guar straw, whereas Moringa and Hedge lucerne leaves showed moderate levels. Saponins play a crucial role in reducing rumen protozoal population, thereby enhancing microbial protein synthesis and reducing methane production.

Condensed tannin levels remained within moderate ranges, which are considered beneficial for ruminant nutrition. Saponin content increased in T_2, therefore suppress rumen protozoa, enhancing microbial protein synthesis and nitrogen utilization. Flavonoid content was highest in Moringa leaves and guar straw, indicating their role as potent antioxidants. Low oxalate and HCN concentrations across all feeds confirm the safety of leaf inclusion at the tested level. Overall, the phytochemical profile of Moringa and Hedge lucerne leaves and leaf incorporated pelleted concentrate feeds indicates enriched diet with beneficial secondary metabolites.

Several researchers have reported the presence of polyphenols and saponins in Moringa and Hedge lucerne leaves. Studies by Alikwe *et al*. (2013), Aye *et al*. (2013), Okiki *et al*. (2015) and Shaikh *et al*. (2025) documented varying levels of tannins, phenolics, flavonoids, saponins, phytates, and other secondary metabolites in Moringa leaves. Similarly, Thirumeignanam *et al*. (2019) and Sarkar *et al*. (2022) reported appreciable concentrations of total phenolics, tannins, saponins, and flavonoids in hedge lucerne leaves, which corroborate the findings of the present study.

Reason behind the marginally higher DPPH radical scavenging activity in Hedge lucerne might be due to differences in polyphenolic composition and hydrogen-donating capacity, as plant phenolics effectively quench DPPH radicals via hydrogen atom and electron transfer mechanisms (Li *et al*., 2018; Shahidi and Ambigaipalan, 2020; Liu *et al*., 2021). Moreover, both leaf sources showed strong DPPH scavenging activity, reflecting their richness in phenolics, flavonoids and condensed tannins (Pérez-Jiménez *et al*., 2019; Koley *et al*., 2022).

Moringa oleifera leaves demonstrated significantly higher total antioxidant capacity, hydroxyl and superoxide radical scavenging activities and metal chelating ability than Hedge lucerne leaves, indicating a broader spectrum of water- and lipid-soluble

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antioxidants (Prieto *et al*., 2018; Vergara-Jimenez *et al*., 2019; Gullón *et al*., 2020; Saleem *et al*., 2021). These enhanced activities showed synergistic effects of flavonoids, non-tannin polyphenols and other redox-active compounds capable of electron donation, radical quenching, and transition-metal chelation (Perron and Brumaghim, 2019; Shahidi and Ambigaipalan, 2020; Santos-Sánchez *et al*., 2024).

Total gas production was numerically higher in T_2 compared with T_1 and T_3, which indicates enhanced fermentative activity of leaf inclusion. Though statistical non-significance but indicates that leaf incorporation did not adversely affect overall rumen fermentation kinetics. The higher *in-vitro* gas production might be due to higher limiting amino acids like lysine and methionine in the protein of moringa leaves (Henuk, 2018) and optimal composition of amino acids with higher digestible protein content (Babiker *et al*., 2017) which is essential for rumen microbial multiplication and growth. Methane production showed a decreasing numerical trend from T_1 to T_3, although differences were not statistically significant. This reduction may be associated with decreased protozoal populations, which are known to harbor methanogens and facilitate interspecies hydrogen transfer. The numerical decline in methane output aligns with the observed shift in VFA profiles and reduced acetate: propionate ratio. The ME and NE values were numerically highest in T_2, reflecting improved energy availability from the diet. This attributed to increased bacterial activity and improved starch and cellulose degradation. The lack of significant differences suggests that energy utilization efficiency was maintained across treatments. Similarly, SCFA concentrations did not differ significantly among treatments, indicating stable fermentation end-product synthesis despite changes in microbial populations and enzyme activities. These findings suggest that leaves-incorporated pelleted concentrate feed can be effectively used as a functional dietary strategy to improve rumen efficiency and potentially reduce environmental impact without compromising fermentation performance.

Several studies have demonstrated the methane-mitigating potential of *Moringa oleifera* in ruminant diets. Abdel-Raheem and Hassan (2021) reported that inclusion of 15% *Moringa oleifera* leaf meal reduced methane production in buffalo calves. Similarly, Badawi *et al*. (2022) observed the lowest CH_4 emission (mg/kg DMI) in Barki male lambs when dried *Moringa oleifera* leaves were supplemented at up to 200 mg/kg BW (≈5 g/day). Kholif *et al*. (2022) showed that replacing concentrate feed with *Moringa oleifera* leaf silage significantly reduced methane generation in ruminants. Lunagariya *et al*. (2022) reported that incorporation of *Moringa oleifera* meal at 5.0%, with incremental levels up to 22.5%, improved *in-vitro* gas production ($P<0.05$) and metabolizable energy content in total mixed rations for growing calves. Bhosale *et al*. (2024) further confirmed that supplementation of *Moringa oleifera* powder at 2% DM, alone or in combination with neem leaf powder and coconut oil, significantly ($P<0.05$) reduced methane emissions in calves.

Conclusion

Incorporation of *Moringa oleifera* and *Desmanthus virgatus* leaves at 10% in pelleted concentrate feeds improved crude protein quality, nitrogen fractions, phytochemical composition and antioxidant activity without adversely affecting *in-vitro* rumen fermentation parameters. Moringa-based diets showed comparatively higher antioxidant potential and numerically improved energy values with reduced methane emission. Thus, these leaves can be effectively utilized as sustainable and cost-effective alternative feed resources in camel nutrition.

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