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Efficacy of *Moringa oleifera* as a ruminant feed supplement: Impacts on intake, growth, digestibility, and fermentation kinetics

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Abstract
This review depicts the current research on the efficacy of *Moringa oleifera* as a dietary supplement for ruminants, evaluating its impact on intake, growth, digestion, and metabolic efficiency. The literature indicates that *Moringa* exerts a dose-dependent influence on voluntary feed intake; while moderate inclusion enhances dry matter and nutrient consumption due to high protein content and palatability, high inclusion rates may inhibit intake due to physical bulk or energy density limitations. Supplementation is consistently associated with improved average daily gain and structural growth, although effects are non-linear and sensitive to the basal diet. Furthermore, *Moringa* foliage significantly enhances nutrient digestibility, particularly of dry matter and crude protein, relative to conventional tropical forages. In the rumen, it shifts fermentation kinetics towards improved energy efficiency by increasing volatile fatty acid production and reducing ammonia nitrogen, with potential benefits for methane mitigation. Collectively, these physiological improvements translate into a superior feed conversion ratio and production efficiency in both growing and lactating animals.

Keywords: *Moringa oleifera*, ruminant nutrition, feed efficiency, rumen fermentation, alternative feed resources, methane mitigation

Introduction
The optimization of ruminant diets through the incorporation of non-conventional feed resources is a critical area of research aimed at improving productivity and economic efficiency. *Moringa oleifera* has emerged as a potent dietary intervention, widely demonstrated to enhance physiological performance due to its high protein content and profile of bioactive compounds that improve nutrient utilization. A substantial body of evidence indicates that replacing conventional concentrate mixtures with *Moringa* leaf meal (MOLM) or hay leads to significant improvements in average daily gain and final body weight (Aharwal *et al*., 2018; Abdel-Raheem *et al*., 2021) [3, 1].
Its application across various ruminant species suggests a versatile role in livestock nutrition. Research consistently highlights that moderate inclusion of *Moringa* enhances dry matter intake (DMI) and nutrient consumption, driven by favorable palatability profiles (Kekana *et al*., 2021; Parmar *et al*., 2021) [16, 23]. Beyond simple mass accumulation, the foliage significantly enhances the digestibility of dry matter and crude protein when replacing lower-quality tropical forages (Roy *et al*., 2016; Imran *et al*., 2016) [24, 14]. Furthermore, *Moringa* supplementation modulates rumen fermentation kinetics, shifting the ecosystem towards improved energy efficiency by enhancing total Volatile Fatty Acid (VFA) production (Yang *et al*., 2019) [35]. These biological changes culminate in improved economic parameters, with studies reporting significantly lower Feed Conversion Ratios (FCR) in supplemented groups compared to controls (Elaidy *et al*., 2017) [11]. This review examines these multifaceted impacts, specifically analyzing regulatory effects on intake, somatic growth, digestibility, and fermentation dynamics.

Composition of *Moringa oleifera* Leaves
The nutritional potential of *Moringa oleifera* as a ruminant feed resource is primarily derived from its rich chemical composition, particularly its high crude protein (CP) content, which compares favorably with traditional protein concentrates like soybean meal

(Soliva *et al*., 2005; Abou-Elezz *et al*., 2011) [32, 2]. However, the proximate analysis profiles reported in the literature exhibit considerable variation (Olson *et al*., 2016) [22]. These discrepancies are largely influenced by agro-climatic conditions, soil fertility, and the stage of physiological maturity at harvest (Moyo *et al*., 2011; Teixeira *et al*., 2014) [20, 33]. Furthermore, the form of processing ranging from air-dried leaves to ground leaf meal significantly alters the dry matter density and fiber fractions (Elaidy *et al*., 2017; Ojiako, 2014) [11, 21]. The following table summarizes the proximate composition of *Moringa* foliage reported across various studies, illustrating the spectrum of nutrient availability that underpins its efficacy as a dietary supplement.

Reference	Form of Leaves	Dry Matter (DM)%	Crude Protein (CP)%	Ether Extract (EE)%	Crude Fiber (CF)%	Ash%
Moyo *et al*. (2011) [20]	Dried Leaves	94.7	30.3	6.5	6.8	7.6
Elaidy *et al*. (2017) [11]	Dry Leaf Meal	91.6	28.0	6.23	15.39	8.43
Salihu *et al*. (2024) [25]	Dried Leaf Powder	86.3	28.5	--	3.0	9.33
Ojiako (2014) [21]	Air-Dried Leaves	85.2	24.5	4.5	17.3	3.8
Abou-Elezz *et al*. (2011) [2]	Leaf Meal	93.7	23.6	4.5	7.9	--
Chatepa & Mbewe (2018) [6]	Seed/Leaf Powder	94.0	28.9	7.8	11.2	7.4
Olson *et al*. (2016) [22]	Leaf Flour	--	25.0 - 30.0	2.0 - 5.0	8.07	11.65
Yameogo *et al*. (2011) [34]	Dried Leaves	--	27.1	7.1	9.1	7.3
Teixeira *et al*. (2014) [33]	Leaf Powder	--	23.0 - 30.3	7.09	5.9	12.0

Modulation of Feed Intake

The incorporation of *Moringa oleifera* into ruminant diets exerts a dose-dependent influence on voluntary feed intake, modulated by the form of supplementation and inclusion levels. Moderate inclusion generally enhances Dry Matter Intake (DMI) and nutrient consumption, attributed to the plant's high crude protein content and favorable palatability. For instance, Kekana *et al*. (2021) [16] observed a linear increase in total DMI in Holstein calves supplemented with *Moringa oleifera* leaf meal (MOLM) up to 16.6 g/100 kg body weight. Similarly, Parmar *et al*. (2021) [23] reported significantly higher intake in Gir calves when *Moringa* leaf hay replaced 25-50% of concentrate protein. This trend is corroborated by Roy *et al*. (2016) [24] and Imran *et al*. (2016) [14], who noted higher DMI in developing bulls and lactating buffaloes fed *Moringa* foliage compared to conventional fodders like maize or alfalfa.

However, the physical bulk and energy density of *Moringa* act as limiting factors at high inclusion rates. Bashar *et al*. (2020) [5] reported a significant reduction in DMI when *Moringa* completely replaced concentrates (100%), suggesting a threshold where palatability or anti-nutritional factors inhibit consumption. Additionally, Elaidy *et al*. (2017) [11] observed that while suckling buffalo calves fed dry *Moringa* leaves had lower overall DMI, they exhibited significantly higher Total Digestible Nutrients (TDN) intake, implying improved energy density induced earlier satiety. Consequently, while *Moringa* enhances nutrient intake, its inclusion must be optimized to balance nutrient density with voluntary feed intake capacity.

Key Findings on Intake Parameters

Reference	Animal Subject	Form & Level of Supplementation	Key Findings on Intake Parameters
Sherasiya *et al*. (2022) [31]	Crossbred Heifers	5% Moringa meal in TMR	No significant difference in DMI, OMI, or CPI. TDN intake significantly reduced ($p<0.01$).
Parmar *et al*. (2021) [23]	Gir Calves	Leaf hay replacing conc. (0, 25, 50, 75%)	Feed intake significantly higher ($p<0.05$) at 25% and 50% replacement levels compared to control and 75% groups.
Kekana *et al*. (2021) [16]	Holstein Calves	Leaf meal (0, 8.33, 16.66 g/100kg BW)	Total DMI and water intake significantly higher in high supplementation group (16.66 g).
Kekana *et al*. (2020) [15]	Holstein Cows	Leaf meal (0, 8.33, 16.66 g/100kg BW)	No significant difference in Total DMI.
Bashar *et al*. (2020) [5]	Lactating Cattle	Moringa feed replacing conc. (0, 50, 100%)	Daily DMI and CPI generally non-significant. Significant reduction in DMI per 100kg BW observed only at 100% replacement.
Shankhpal *et al*. (2019) [28]	Crossbred Cows	Green fodder replacing Napier grass	DMI not affected ($P>0.05$) by incorporation of Moringa fodder.
Malik *et al*. (2019) [18]	Bali Cattle	Urea Molasses Moringa Block (5, 10, 15%)	DMI and OMI differed non-significantly ($P>0.05$) compared to control block.
Yang *et al*. (2019) [35]	Dairy Cows	Leaves/peduncles replacing alfalfa (10.85%)	Significantly higher DMI (P=0.03), NDF intake, and ADF intake. CPI was non-significant.
Dong *et al*. (2019) [10]	Holstein Cows	Dietary supplementation (0, 3, 6, 9%)	DMI was similar across all four treatment groups.
Aharwal *et al*. (2018) [3]	Buffalo Calves	10% Leaf meal replacing calf starter	Total DMI non-significant. CP intake was significantly higher ($P<0.05$) in the Moringa group.
Fattah *et al*. (2017) [13]	Bali Cattle	Moringa powder in diet (0, 5, 10, 15%)	Intake of CF, CHO, and NFE showed no significant difference among treatments.
Elaidy *et al*. (2017)	Buffalo Calves	Dry leaves in starter (0, 5, 10,	DMI significantly lower ($P<0.05$) in supplemented groups (5-

[11]		15, 20%)	15%). However, TDN and DCP intake were significantly higher.
Imran *et al*. (2016) [14]	Lactating Buffaloes	*Moringa oleifera* hay vs. *Medicago sativa*	Total DMI and OMI were significantly higher ($P<0.05$) in the Moringa hay group.
Roy *et al*. (2016) [24]	Developing Bulls	Moringa fodder vs. Maize/Jumbo silage	Daily DMI, OMI, and CPI were significantly higher ($P<0.01$) in bulls fed Moringa foliage compared to controls.
Zeng *et al*. (2016) [36]	Holstein Cows	Silage replacing alfalfa/maize	DMI was non-significant ($p>0.05$) across low, high, and control groups.
Cohen-Zinder *et al*. (2016) [7]	Lactating Cows	Ensiled Moringa mixture in TMR	Voluntary DMI showed no significant difference (P=0.09) compared to control.
Dahlanuddin *et al*. (2014) [8]	Weaned Bali Cattle	Moringa hay vs. other tree legumes	DMI significantly higher than Gliricidia hay, but lower than Leucaena or Sesbania hay. ME intake lower than Leucaena.
Mendieta-Araica *et al*. (2011) [19]	Dairy Cows	Fresh vs. Ensiled Moringa	DMI, OMI, CPI, NDF, and ADF intakes were significantly higher in fresh and ensiled Moringa groups compared to control.
Sanchez *et al*. (2005) [26]	Creole Dairy Cows	2 kg and 3 kg DM Moringa supplementation	Total DMI significantly higher ($P<0.05$) in supplemented groups; intake increased with supplementation level.

DMI: Dry Matter Intake; OMI: Organic Matter Intake; CPI: Crude Protein Intake; TMR: Total Mixed Ration; TDN: Total Digestible Nutrients; DCP: Digestible Crude Protein; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; ME: Metabolizable Energy.

Growth Performance and Biometrics

Moringa oleifera supplementation consistently enhances growth performance, primarily due to its high protein content and bioactive compounds. Research indicates that replacing conventional concentrates with *Moringa* leaf meal (MOLM) improves Average Daily Gain (ADG) and final body weight. In buffalo calves, Aharwal *et al*. (2018; 2019) [3, 4] and Abdel-Raheem *et al*. (2021) [1] observed that substituting 10-15% of concentrates significantly improved weight gain compared to controls. This effect is dose-dependent; Parmar *et al*. (2021) [23] and Elaidy *et al*. (2017) [11] noted that while moderate inclusion (25-50% replacement or 5-15% inclusion) maximized gain, higher rates resulted in diminished performance.

Effect on skeletal development varies. Kekana *et al*. (2021) [16] reported a linear increase in heart girth and body length in Holstein calves supplemented with MOLM up to 16.66 g/100 kg BW. Conversely, Sherasiya *et al*. (2022) [31] found that while 5% Moringa meal maintained body weight parity in crossbred heifers, it resulted in significantly lower heart girth and body length. Furthermore, Dahlanuddin *et al*. (2014) [8] found that weaned Bali cattle fed *Moringa* hay exhibited lower live weight gains compared to those fed *Leucaena* or *Sesbania* hay, indicating comparative efficiency depends on the basal diet. High inclusion rates may also limit specific skeletal growth parameters due to energy constraints. Sharma *et al*. (2024) [29] observed that replacing 50% of calf starter protein with *Moringa* foliage resulted in a significantly lower gain in wither height compared to controls, attributed to a reduced intake of metabolizable energy and crude protein despite similar dry matter intake

Key Findings on Growth Parameters

Reference	Animal Subject	Form & Level of Supplementation	Key Findings on Growth Parameters
Sherasiya *et al*. (2022) [31]	Crossbred Heifers	5% Moringa meal in TMR	Weight gain and final BW non-significant. Heart girth and body length significantly lower ($P<0.05$) in Moringa group.
Parmar *et al*. (2021) [23]	Gir Calves	Leaf hay replacing conc. (0, 25, 50, 75%)	Overall BW gain and ADG significantly higher ($p<0.05$) at 25% and 50% replacement levels compared to control and 75% groups.
Abdel-Raheem *et al*. (2021) [1]	Buffalo Calves	Leaf meal (15%, 20%) replacing soybean	Final BW significantly higher at 15%. ADG significantly increased ($p<0.001$) for both 15% and 20% levels.
Kekana *et al*. (2021) [16]	Holstein Calves	Leaf meal (0, 8.33, 16.66 g/100kg BW)	Significant increase ($P<0.01$) in heart girth, body length, and final BW at high supplementation (16.66 g).
Aharwal *et al*. (2019) [4]	Buffalo Calves	Leaf meal (5%, 15%) replacing starter	Significant increase ($P<0.05$) in BW gain (10.57% and 12.63% increase over control for M5 and M15, respectively).
Aharwal *et al*. (2018) [3]	Buffalo Calves	10% Leaf meal replacing starter	Significantly higher ($P<0.05$) final BW and ADG (8.30% increase over control).
Elaidy *et al*. (2017) [11]	Buffalo Calves	Dry leaves (0, 5, 10, 15, 20%) in starter	Total BW gain and ADG significantly higher ($P<0.05$) in 5%, 10%, and 15% groups compared to control and 20% group.
Cohen-Zinder *et al*. (2016) [7]	Lactating Cows	Ensiled Moringa mixture in TMR	Body weight change (0.34 kg/d) was non-significant (P=0.09) compared to control (0.35 kg/d).
Dahlanuddin *et al*. (2014) [8]	Weaned Bali Cattle	Moringa hay vs. other tree legumes	Live weight gain, wither height, and chest girth significantly lower ($P<0.05$) compared to *Leucaena* and *Sesbania* hay groups.

BW: Body Weight; ADG: Average Daily Gain; TMR: Total Mixed Ration; MOLM: Moringa Oleifera Leaf Meal.

Nutrient Digestibility

Moringa oleifera generally enhances digestibility, particularly when replacing lower-quality tropical forages. Roy *et al*. (2016) [24] and Imran *et al*. (2016) [14] observed significantly higher digestibility coefficients for DM, OM, and CP in animals fed *Moringa* compared to maize silage or alfalfa hay. This is supported by Khalel *et al*. (2014) [17] and Sanchez *et al*. (2005) [26], who reported improvements in TDN and fiber digestibility (NDF, ADF) with *Moringa* supplementation.

However, results can vary based on the substituted Ingredient. While Elaidy *et al*. (2017) [11] found improved digestibility across all parameters with 5-15% inclusion, Abdel-Raheem *et al*. (2021) [1] noted that replacing soybean with *Moringa* reduced CP and ether extract (EE) digestibility. Processing also influences outcomes; Mendieta-Araica *et al*. (2011) [19] demonstrated that ensiled *Moringa* yielded higher digestibility than fresh foliage. Conversely, Cohen-Zinder *et al*. (2016) [7] and Zeng *et al*. (2016) [36] found that high inclusion of *Moringa* silage could depress DM and NDF digestibility, highlighting the need for balanced inclusion rates.

Key Findings on Digestibility

Reference	Animal Subject	Form & Level of Supplementation	Key Findings on Digestibility
Sherasiya *et al.* (2022) [31]	Crossbred Heifers	5% Moringa meal in TMR	No significant difference in digestibility of DM, OM, CP, CF, NFE, NDF, or ADF.
Sherasiya (2021) [30]	-	5% & 7.5% meal in TMR	Digestibility of all nutrients was not significantly influenced compared to control.
Abdel-Raheem *et al.* (2021) [1]	Buffalo Calves	Leaf meal (15%, 20%) replacing soybean	Significantly improved (*P*<0.05) DM, OM, and CF digestibility. However, CP and EE digestibility significantly decreased.
Bashar *et al.* (2020) [5]	Lactating Cattle	Moringa feed replacing conc. (0, 50, 100%)	Digestibility coefficients of DM and CP were non-significant across treatments.
Malik *et al.* (2019) [18]	Bali Cattle	Urea Molasses Moringa Block (5, 10, 15%)	DM and OM digestibility significantly higher (*P*<0.05) in 10% and 15% groups compared to control.
Fattah *et al.* (2017) [13]	Bali Cattle	Moringa powder (0, 5, 10, 15%)	CF, Carbohydrate, and NFE digestibility showed no significant difference (*P*>0.05).
Elaidy *et al.* (2017) [11]	Buffalo Calves	Dry leaves (0, 5, 10, 15, 20%) in starter	Digestibility of OM, CP, CF, EE, and NFE significantly higher (P<0.05) in 5-15% groups compared to control.
Imran *et al.* (2016) [14]	Lactating Buffaloes	*Moringa oleifera* hay vs. *Medicago sativa*	Apparent digestibility of DM, OM, CP, NDF, ADF, and EE significantly higher (*P*<0.05) in Moringa hay group.
Zeng *et al.* (2016) [36]	Holstein Cows	Silage replacing alfalfa/maize	CP and ADF digestibility non-significant. High Moringa group had significantly lower DM and NDF digestibility.
Roy *et al.* (2016) [24]	Developing Bulls	Moringa fodder vs. Maize/Jumbo silage	Moringa leaves exhibited significantly higher (*p*<0.001) DM, CP, and OM digestibility than controls.
Cohen-Zinder *et al.* (2016) [7]	Lactating Cows	Ensiled Moringa mixture in TMR	Control group had significantly higher (P=0.01) digestibility of DM, NDF, cellulose, and CP than Moringa group.
Khalel *et al.* (2014) [17]	Friesian Cows	Moringa vs. Berseem (40%, 20%)	Digestibility of DM, OM, CP, CF, EE, and NFE significantly higher (*P*<0.05) in 40% Moringa ration. Nitrogen utilization increased.
Dahlanuddin *et al.* (2014) [8]	Weaned Bali Cattle	Moringa hay vs. other tree legumes	Moringa hay had significantly higher DM digestibility than *Sesbania* and *Leucaena* hay.
Mendieta-Araica *et al.* (2011) [19]	Dairy Cows	Fresh vs. Ensiled Moringa	Digestibility of DM, CP, OM, NDF, and ADF significantly higher (*P*<0.05) in ensiled and fresh Moringa groups compared to control.
Sanchez *et al.* (2005) [26]	Creole Dairy Cows	2 kg and 3 kg DM Moringa supplementation	Digestibility of DM, CP, NDF, and ADF significantly higher (P<0.05) in supplemented groups compared to hay-only control.

DM: Dry Matter; OM: Organic Matter; CP: Crude Protein; CF: Crude Fiber; EE: Ether Extract; NFE: Nitrogen Free Extract; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; TMR: Total Mixed Ration

Rumen Fermentation

Moringa oleifera supplementation modulates rumen fermentation kinetics, typically enhancing energy efficiency. Yang *et al.* (2019) [35] and Khalel *et al.* (2014) [17] demonstrated that replacing roughages with *Moringa* significantly increased total Volatile Fatty Acid (VFA) concentrations, particularly acetate and propionate. Concurrently, *Moringa* optimizes nitrogen metabolism; Bashar *et al.* (2020) [5] and Yang *et al.* (2019) [35] reported significant reductions in ruminal ammonia nitrogen (NH_3-N), indicating more efficient capture for microbial protein synthesis. This is substantiated by Shankhpal *et al.* (2019) [28], who observed higher microbial nitrogen yield in cows fed *Moringa* fodder. Additionally, *Moringa* shows potential for methane mitigation. *In vitro* assays by Soliva *et al.* (2005) [32] and Sarkar *et al.* (2016) [27] showed methane (CH_4) reductions of up to 17% compared to soybean meal.

Key Findings on Fermentation Parameters

Reference	Subject / Method	Form & Level of Supplementation	Key Findings on Fermentation Parameters
Bashar *et al.* (2020) [5]	Lactating Cattle	Feed replacing conc. (50, 100%)	Significantly higher VFA; significantly lower NH_3. CH_4 showed numerical reduction but was statistically non-significant. Rumen pH was unaffected.
Yang *et al.* (2019) [35]	Dairy Cows	Leaves/peduncles replacing alfalfa (10.85%)	Significantly lower NH_3-N (P=0.02). Significantly higher total VFA, acetate, propionate, and butyrate concentrations.
Shankhpal *et al.* (2019) [28]	Crossbred Cows	Green fodder replacing Napier grass	Intestinal microbial nitrogen flow increased significantly (*P*<0.01), indicating higher microbial protein yield.
Elghandour *et al.* (2017) [12]	*In vitro* (Goat/Steer)	Leaf meal replacing soybean meal (0-100%)	Decreased SCFA concentrations and asymptotic gas production. Increased CO_2 production and OM degradability.
Sarkar *et al.* (2016) [27]	*In vitro* (Wheat straw)	Leaf meal (0, 5, 10, 15%)	Significant increase in total gas production, acetate, and propionate. Significant reduction in CH_4% and volume at 10-15% levels.
Khalel *et al.* (2014) [17]	Friesian Cows	Fodder vs. Berseem (40%, 20%)	Significantly lower pH and NH_3-N. Significantly higher VFA concentration (approx. 30% increase) and microbial N yield.
Dey and Paul (2014) [9]	*In vitro* (Buffalo)	Leaves + Wheat straw	Significantly higher gas production and SCFA synthesis compared to wheat straw alone. Lower methane emission intensity.
Soliva *et al.* (2005) [32]	*In vitro* (RUSITEC)	Whole/Extracted Leaves vs. Soybean	Daily methane emission was 17% lower (*P*<0.05) with unextracted Moringa compared to soybean/rapeseed meal. Higher OM degradation.

VFA: Volatile Fatty Acids; NH_3-N: Ammonia Nitrogen; CH_4: Methane; SCFA: Short Chain Fatty Acids; OM: Organic Matter; conc.: concentrate.

Feed Conversion Efficiency

Moringa oleifera generally improves the Feed Conversion Ratio (FCR). Elaidy *et al*. (2017) [11] and Abdel-Raheem *et al*. (2021) [1] reported that buffalo calves fed 5-15% *Moringa* leaf meal exhibited significantly lower FCR compared to control groups. Similarly, Roy *et al*. (2016) [24] found better feed conversion in bulls fed *Moringa* foliage compared to maize[80].

The relationship can be non-linear. Parmar *et al*. (2021) [23] observed the best efficiency in Gir calves at the highest replacement level (75%), contrasting with other studies suggesting diminished returns at high rates. In lactating animals, Khalel *et al*. (2014) [17] demonstrated that replacing *Trifolium alexandrinum* with *Moringa* fodder improved efficiency, requiring approximately 18% less dry matter per kg of 4% Fat-Corrected Milk (FCM).

Key Findings on Feed Efficiency / FCR

Reference	Animal Subject	Form & Level of Supplementation	Key Findings on Feed Efficiency / FCR
Sherasiya *et al*. (2022) [31]	Crossbred Heifers	5% Moringa meal in TMR	FCR based on DM, CP, DCP, and TDN showed non-significant differences between control and treatment groups.
Parmar *et al*. (2021) [23]	Gir Calves	Leaf hay replacing conc. (0, 25, 50, 75%)	FCR (feed intake/kg gain) significantly improved in all treatment groups. Lowest FCR (best efficiency) observed in T4 (75% replacement).
Abdel-Raheem *et al*. (2021) [1]	Buffalo Calves	Leaf meal (15%, 20%) replacing soybean	FCR significantly improved (*p*<0.001) at both 15% and 20% inclusion levels compared to control.
Elaidy *et al*. (2017) [11]	Buffalo Calves	Dry leaves (0, 5, 10, 15, 20%) in starter	Significantly better FCR (lower kg DMI/kg gain) in 5%, 10%, and 15% groups compared to control and 20% group.
Roy *et al*. (2016) [24]	Developing Bulls	Moringa fodder vs. Maize/Jumbo silage	Moringa foliage resulted in significantly better feed conversion (1.30 kg gain/kg DM) compared to Maize (1.00) or Jumbo silage (0.88).
Khalel *et al*. (2014) [17]	Friesian Cows	Fodder vs. Berseem (40%, 20%)	Feed efficiency (kg DM/kg 4% FCM) significantly improved (*P*<0.05) by approx. 18% (R2) and 13% (R3) compared to control.

FCR: Feed Conversion Ratio; DM: Dry Matter; CP: Crude Protein; DCP: Digestible Crude Protein; TDN: Total Digestible Nutrients; FCM: Fat-Corrected Milk.

Conclusion

The cumulative evidence positions *Moringa oleifera* as a strategic nutritional intervention for optimizing ruminant production systems. By effectively replacing expensive protein concentrates, *Moringa* supplementation not only supports superior growth performance and nutrient digestibility but also enhances metabolic efficiency through the favorable modulation of rumen fermentation kinetics. However, the benefits are strictly dose-dependent; while moderate inclusion maximizes voluntary intake and feed conversion, excessive substitution may yield diminishing returns due to physical bulk or metabolic satiety. Ultimately, the integration of *Moringa* represents a sustainable pathway to reduce feed costs and potentially mitigate environmental impacts through methane reduction, provided that inclusion levels are carefully calibrated to the specific physiological requirements of the animal and the nutritional baseline of the diet.

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