

Feed intake and in vitro dry matter digestibility in dairy cows fed different levels of dried *Moringa oleifera* leaves and *Medicago sativa* hay as a supplement to *Chloris gayana* hay

Omolara Latifat Alarape (✉ alarapeomolaralatifat616@gmail.com)

Egerton University Faculty of Agriculture <https://orcid.org/0009-0004-5259-2543>

Perminus K. Migwi

Egerton University Faculty of Agriculture

James O. Ondiek

Egerton University Faculty of Agriculture

Research Article

Keywords: Fermentation, Gas production, Lucerne, Moringa, Rhodes grass, Short-chain fatty acids

Posted Date: September 19th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-3292570/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

The effect of supplementing Rhodes grass hay with different levels of dried Moringa (*Moringa oleifera*) leaves and Lucerne hay on feed intake and *in vitro* digestibility were studied using lactating dairy cows. Nine lactating Holstein-Friesian cows with initial body weight of 444 ± 39.7 kg were randomly assigned to three experimental treatments using a Randomised Complete Block Design (RCBD). Rhodes grass hay was fed *ad libitum* while Moringa leaves and Lucerne hay were supplemented at the ratio 0:10 in T1, 5:5 in T2 and 10:0 in T3 respectively. Moringa supplementation increased ($p < 0.05$) the DM intake of the basal diet (13.7 kg DM/day) and the total DM intake (15.3 kg DM/day). The Moringa-supplemented treatment (T3) produced the highest gas (8.93 ml/200mg DM) at 24 hr, has the highest SCFA (0.19 ml/200mg DM) and ME (6.86 MJ/kg DM) but the least organic matter digestibility (20.7%) when compared to the control. The results showed that the use of dried Moringa leaves as a protein supplement to low quality diets improved the DM intake and the digestibility of the diet which can lead to an increase in dairy productivity.

1. Introduction

In most developing countries, the insufficiency and poor quality of forage are major constraints to improvement in livestock productivity. In addition to an inadequate year-round supply of high-quality forage, the availability and cost of high-quality concentrates and supplementary feeds are significant global issues in the livestock sector, particularly for smallholder dairy farmers (Hao et al., 2017).

Milk production in Kenya accounts for a significant portion of the economy, estimated at about 5% of GDP (KALRO, 2022) and majority of this dairy producers are smallholder dairy farmers as they account for up to 70–80% of Kenya's dairy producers (Wambugu et al., 2011). They are challenged by many factors, which include inadequate feed and feeding which has led to poor feeding regime that inevitably leads to low milk yield and quality (Mutavi et al., 2016). One possible option to this challenge is the exploration of alternative feed resources such as non-conventional protein-rich forage trees with high nutrient content, a balanced profile of amino acids, a reasonable cost, and a large proportion of digestible fibre, which can supplement protein and energy in the animals during periods of feed scarcity (Silanikove, 2000).

During the dry season, livestock farmers with limited access to feed resources may find it advantageous to use fodder trees and shrubs to improve the quality and availability of feed for their animals, as the trees are a good and inexpensive source of protein and micronutrients (Moyo et al., 2012). In this regard, the drought-tolerant Moringa (*Moringa oleifera*) tree can be considered one of the numerous top feed resources in the tropics.

Moringa is a tree native to India but has spread to many tropical and sub-tropical areas worldwide. It's a perennial evergreen tree (Palada et al., 2007) whose forage contains approximately 5.9% moisture, 38.6% carbohydrates, 27.2% protein, and 17.1% fat (Yameogo et al., 2011). Benefits of using Moringa as a source of forage for ruminants include its versatility as a forage tree, which allows for multiple harvests throughout the growing season and the storage of its dried leaves for extended periods without loss of nutritional content (Mendieta-Araica et al., 2011). Numerous studies have demonstrated that Moringa can enhance the nutrition of ruminants via microbial protein synthesis (Soliva et al., 2005) and decrease in the retention time of feed. Moringa also contains large quantities of active substances, such as flavonoids, and other phenolic compounds which regulates the rumen microflora to enhance digestibility and feed intake (Kholif et al., 2016).

However, there is little information on the feeding value of dried *Moringa oleifera* leaves in relation to dairy cow performance in Kenya. Therefore, this study aimed to determine the effect of supplementing different levels of Moringa leaves to dairy cows fed a basal diet of Rhodes grass hay on feed intake and digestibility.

2. Materials and Methods

2.1 Study Site

This study was conducted at Tatton Agriculture Park (TAP), Egerton University, Njoro, Kenya. It is located between longitude 35° 57'E and latitude 0° 23'S at an elevation of 2,200 and 2,280 m above sea level, with a daily mean temperature of 21°C. The precipitation pattern is bimodal, with mean annual precipitation between 900 and 1,020 mm. The long rain occurs between March and May, occasionally extending into June, and the short rain occurs between September and November.

2.2 Experimental Animals and Design

A total of nine lactating Holstein-Friesian cows weighing 444 ± 39.7 kg were housed in sheltered cubicles within the vicinity of the University Biogas unit. They were randomly assigned to three experimental groups of three animals each, using a Randomised Complete Block Design (RCBD). During the first week of the feeding trial, the animals were drenched with an anthelmintic to control internal parasites and sprayed weekly to control external parasites.

2.3 Experimental Diets and Treatments

Rhodes grass (*Chloris gayana*) hay served as the basal diet, while Lucerne (*Medicago sativa*) hay and dried Moringa (*Moringa oleifera*) leaves were used as supplements. Rhodes grass hay was acquired from neighbouring stores, and Lucerne hay was acquired from Kenya Agriculture and Livestock Research Organisation (KALRO), Naivasha. The hay was shredded using a fodder chopper and stored in gunny bags. Moringa leaves were sourced from Kiorimba/Machegene, Meru County, Kenya. The leaves were removed from the branches, air-dried on plastic sheets under partial shade, and then stored in gunny bags.

The cows were fed three different experimental diets, as stated in Table 1, and were randomly assigned to one of three treatments as follows: -

- 1. T1: The basal diet with 0% Moringa (10% Lucerne); control
- 2. T2: The basal diet with 5% supplementation of Moringa (5% Moringa + 5% Lucerne);
- 3. T3: The basal diet with 10% supplementation of Moringa (10% Moringa).

Table 1
Composition of dietary treatments

Ingredients	Dietary treatments		
	T1 (Control)	T2	T3
Dried Moringa leaves (%)	0	5	10
Lucerne hay (%)	10	5	0
Rhodes grass hay (%)	90	90	90
Total (%)	100	100	100

Dry matter intake (DMI) was estimated as 4% of the live weight of each cow, the supplements (Moringa leaves and Lucerne hay) were fed at 10% of the total estimated daily DMI for each cow, and the basal diet (Rhodes grass hay) was offered *ad libitum*.

2.4 Proximate Analysis of Feed Ingredients

The feed ingredients were analysed for crude protein (CP), ether extract (EE) and ash using method 984.13, method 920.39, and method 942.05 of the Association of Analytical Chemists' official procedures respectively (AOAC, 2005) and neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined in accordance with Van Soest et al. (1991).

2.5 Estimation of Feed Intake

The basal diets were offered to each cow *ad libitum* at 08:00 hr, 13:00 hr, and 16:00 hr, and to ensure that the supplement was wholly consumed, it was provided prior to *ad libitum* feeding of the basal diet. The basal diet was also adjusted based on the previous day's intake to ensure that the cow receives sufficient basal feed without leaving too many leftovers and to avoid selective feeding. There was also unlimited access to water and a complete mineral supplement. The feeding trial lasted for eight (8) weeks, with two prior weeks assigned to adaptation to the treatments.

Daily records of the quantity of feed supplied and the amount of leftovers were kept. The feed intake on a dry matter basis and the total dry matter intake (TDMI) were estimated based on the daily differences between the amount of feed offered and the refusals:

1. DMI of the basal diet (kg DM/day) = Basal diet offered (kg) - Basal diet refused (kg)
2. TDMI (kg DM/day) = DMI of the basal diet (kg) + DMI of the supplement (kg)

2.6 Determination of *in vitro* Dry Matter Digestibility

During the last week of the feeding trial, rumen liquor was collected manually from the animals using a stomach tube connected to a vacuum pump 3 hr after the morning feeding (Lodge-Ivey et al., 2009). Feed particles were removed from the rumen liquor by straining it through four layers of cheesecloth and it was used to evaluate digestibility.

To evaluate digestibility, the experimental diets, and supplements were subjected to *in vitro* gas production following the procedures of Tilley & Terry (1963) as modified by Menke & Steingas (1988). The samples were placed in calibrated glass syringes with Vaseline-lubricated pistons and then incubated with the rumen liquor and buffer mixture in a water bath maintained at 39°C. The gas production at 0, 3, 6, 9, 12, 24, 48, 72, and 96 hr were recorded and used to determine *in vitro* dry matter digestibility (IVDMD).

Cumulative gas production data were fitted into the exponential model of Ørskov & McDonald (1979) using the Nway Excel program, and the degradation curve was described as

$Y = a + b(1 - e^{-ct})$ where: Y – the gas produced

a – the soluble fraction

b – the degradable fraction that is degraded at time t

a + b – the potential gas produced

c – the gas production rate constant

t – the incubation time

A graph was plotted to illustrate the progression of the incubation process. The gas generated was also utilized to estimate short-chain fatty acids (SCFA), metabolizable energy (ME), and organic matter digestibility (OMD) as

- SCFA (mmol/200mg DM) = (0.0222*GP24)-0.00425, where GP24 is 24h net gas production (Getachew et al., 2002)

- $OMD (\%) = 18.53 + (0.9239 \cdot GP48) + (0.0540 \cdot CP)$, where GP48 is 48h net gas production, and CP is crude protein (Menke & Steingas, 1988)
- $ME (MJ/kg DM) = 2.2 + (0.1357 \cdot GP24) + (0.0057 \cdot CP) + (0.0002859 \cdot EE^2)$ where GP24 is 24h net gas production, CP is crude protein, and EE is ether extract (Menke & Steingas, 1988).

2.7 Statistical Analysis

Data were subjected to an analysis of variance (ANOVA) procedure following a Randomised Complete Block Design (RCBD) using the Generalized Linear Model (GLM) procedure of SAS (SAS 2009). The different means were separated using Tukey's Studentized Range (HSD) Test at $P = 0.05$. The statistical model of Randomised Complete Block Design (RCBD) was used:

$Y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij}$; where: Y_{ij} - the j^{th} observation of the i^{th} treatment

μ - the population mean

α_i - the effect of the i^{th} treatment, $i = \{1, 2, 3\}$

β_j - the effect of the j^{th} block

ϵ_{ij} - the random error of the i^{th} treatment on the j^{th} block

3. Results

3.1 Chemical composition of feed ingredients

The chemical composition of the feed ingredients used in this study are presented in Table 2. Moringa leaves had the highest CP ($295 \text{ g kg}^{-1} \text{ DM}$) and crude fat ($82.5 \text{ g kg}^{-1} \text{ DM}$) but low NDF ($138 \text{ g kg}^{-1} \text{ DM}$) while Rhodes grass hay has the least CP ($107 \text{ g kg}^{-1} \text{ DM}$) and a very high NDF ($743 \text{ g kg}^{-1} \text{ DM}$).

Table 2
Chemical composition of feed ingredients^a

Composition ($\text{g kg}^{-1} \text{ DM}$)	Feed ingredients		
	Rhodes grass hay	Lucerne hay	Moringa leaves
CP	107 ± 5.39	207 ± 6.92	295 ± 2.56
EE	34.8 ± 1.02	20.4 ± 0.01	82.5 ± 1.44
Ash	103 ± 0.99	128 ± 1.38	124 ± 1.29
NDF	743 ± 6.26	428 ± 5.21	138 ± 1.78
ADF	413 ± 5.28	336 ± 3.66	137 ± 1.79
ADL	32.5 ± 3.78	52.7 ± 1.95	12.1 ± 0.84
^a Means and standard deviation; CP = crude protein; EE = ether extract; NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin			

3.2 Feed Intake

The feed intake was assessed based on the DMI of the basal diet and the TDMI for each cow. The result (Table 3) shows that cows supplemented with Moringa leaves (T3) had the highest (13.7 kg DM/day) DMI followed by those supplemented with Lucerne hay (T1). The highest (15.3 kg DM/day) TDMI was also recorded in the cows supplemented with Moringa leaves (T3), followed by those supplemented with Moringa leaves and Lucerne hay (T2). The DMI of the basal diet and TDMI was different ($P = 0.05$) among all the treatments, and the highest feed intake was recorded in the Moringa-supplemented treatment (T3). This study shows that supplementation with Moringa leaves enhanced feed intake ($P = 0.05$).

Table 3

Feed intake of lactating Holstein-Friesian cows supplemented with different levels of Moringa leaves and Lucerne hay

Dietary treatments	Feed intake (kg DM/day)	
	DMI of the basal diet	TDMI
T1 (control)	13.3 ^b	15.1 ^a
T2	12.5 ^c	14.3 ^b
T3	13.7 ^a	15.3 ^a
SEM	0.09	0.09
P	< .0001	< .0001
^{abc} Means in the same row without common letter are different at ($P < 0.05$; T1 = Rhodes grass hay supplemented with Lucerne hay; T2 = Rhodes grass hay supplemented with Lucerne hay and Moringa leaves; T3 = Rhodes grass hay supplemented with Moringa leaves; SEM = Standard error of the mean; DMI = Dry matter intake; TDMI = Total dry matter intake		

3.3 *In vitro* Gas Production and Fermentation Characteristics

The result of the *in vitro* gas production and fermentation characteristics of the experimental diets and supplements are presented in Table 4. It shows that T3 (8.93 ml/200mg DM) produced the highest gas at 24 hr of incubation, while T1 (2.38 ml/200mg DM) produced the least. At 48 hr of incubation, T3 (1.42 ml/200mg DM) produced the least gas, and there was no significant difference between T4, T5, and T6.

The initial gas production (A) was highest in T5 (1.41 ml/200mg DM), and no significant difference was across the treatments. The highest actual gas production (B) was recorded in T2 (5.60 ml/200mg DM), and there was no significant difference between T1, T3, T4, T5, and T6. The rate of gas production (C) was highest in T6 (8.18 ml/200mg DM), but there was no significant difference across the treatments. The total gas production (A + B) does not follow the same pattern as A and B as the highest gas was produced by T2 (7.18 ml/200mg DM), and there was no significant difference between T1, T3, T4, T5, and T6. The residual standard deviation (RSD) also varies, with T3 (2.84) having the highest and other treatments showing no significant difference.

Moringa-supplemented treatment produced the highest (0.19 ml/200mg DM) short-chain fatty acids (SCFA), and there was no significant difference across the treatments. The organic matter digestibility (OMD) was highest in T2 (29.9%), and the least was recorded in T3 (20.7%). T6 (6.86 MJ/kg DM) has the highest metabolizable energy (ME) while T1 (3.44 MJ/kg DM) has the least, and there was no significant difference between T2, T3, T4, and T5.

Table 4

Effect of supplementing lactating Holstein-Friesian cows with different levels of Moringa leaves and Lucerne hay on *in vitro* gas production and fermentation characteristics

Dietary treatments	GP24	GP48	A	B	C	A + B	RSD	SCFA	OMD	ME
T1	2.38 ^a	9.02 ^b	0.57 ^a	4.09 ^b	0.04 ^a	4.66 ^b	2.82 ^a	0.05 ^a	27.7 ^b	3.44 ^c
T2	5.02 ^a	11.4 ^a	1.22 ^a	5.60 ^a	0.05 ^a	7.18 ^a	2.54 ^a	0.11 ^a	29.9 ^a	3.99 ^{bc}
T3	8.93 ^a	1.42 ^d	0.27 ^a	3.40 ^b	0.10 ^a	3.66 ^b	2.84 ^a	0.19 ^a	20.7 ^d	4.37 ^b
T4	4.08 ^a	5.61 ^c	0.21 ^a	3.04 ^b	0.07 ^a	3.25 ^b	1.64 ^a	0.09 ^a	24.8 ^c	4.05 ^{bc}
T5	5.62 ^a	6.64 ^c	1.41 ^a	3.17 ^b	7.47 ^a	4.58 ^b	2.23 ^a	0.12 ^a	26.0 ^{bc}	4.83 ^b
T6	7.59 ^a	4.88 ^c	1.08 ^a	3.05 ^b	8.18 ^a	4.13 ^b	2.56 ^a	0.16 ^a	24.6 ^c	6.86 ^a
SEM	0.68	0.78	0.17	0.27	1.08	0.32	0.19	0.02	0.71	0.27
p	0.1086	<.0001	0.3877	0.0018	0.0216	<.0001	0.5788	0.1087	<.0001	<.0001
^{abcd} Means in the same column without common letter are different at $p < 0.05$; T1 = Rhodes grass hay supplemented with Lucerne hay; T2 = Rhodes grass hay supplemented with Lucerne hay and Moringa leaves; T3 = Rhodes grass hay supplemented with Moringa leaves; T4 = Lucerne hay; T5 = Lucerne hay and Moringa leaves; T6 = Moringa leaves; SEM = Standard error of the mean; GP24 = gas production at 24 hr; GP48 = gas production at 48 hr; A = initial gas produced; B = actual gas produced during degradation; C = the rate of gas production per hr; A + B = the total gas produced during fermentation; RSD = Residual Standard Deviation; SCFA = short chain fatty acids; OMD = organic matter digestibility; ME = Metabolizable energy										

Figure 1 presents the *in vitro* gas production measured at 0, 3, 6, 9, 12, 24, 48, 72, and 96 hr and shows the trends in the fermentation of the diets and supplements. This shows that T2 has the highest degradability. It can also be observed that the highest level of degradation for all the samples except T3 was observed at 48 hr before they started declining.

4. Discussion

4.1 Chemical composition of feed ingredients

The Rhodes grass hay utilised in this experiment was of typical dry season quality, with low CP ($107 \text{ g kg}^{-1} \text{ DM}$) and high NDF ($743 \text{ g kg}^{-1} \text{ DM}$). Low-quality forage, as defined by Leng (1990), is forage with a low CP, which leads to a decrease in DM intake due to the low nitrogen concentration, and such forages require supplementation with appropriate nutrients (such as protein supplementation) to achieve maximum productivity.

The average CP of Moringa leaves that were utilised in this experiment is $295 \text{ g kg}^{-1} \text{ DM}$, which is within the range of values reported by Wu et al. (2013) and confirms its suitability as a protein supplement that can increase DM intake in diets with low quality forage, resulting in an additive effect of basal diets and supplements (Sánchez et al., 2006).

4.2 Feed Intake

Feed intake is essential in ruminant production because it's the major factor influencing production efficiency and health of the animals, but it depends on some factors such as palatability, digesta flow rate, and fibre content (Kholif et al., 2016).

The result of this study shows that there was an increase in the feed intake in dairy cows supplemented with Moringa leaves (13.7 kg DM/day) compared to those supplemented with Lucerne hay (13.3 kg DM/day) or the combination of Moringa leaves and Lucerne hay (12.5 kg DM/day). The higher feed intake in Moringa-supplemented cows indicates that it is more palatable and acceptable to dairy cows.

The increased feed intake can also result from the low rumen degradability of Moringa leaves, as it has been reported that a decrease in ruminal protein degradation increases feed intake (Kholif et al., 2014). The increased intake observed may also result from increased microbial activity in relation to the increased essential nutrients available to the rumen microbes (Su & Chen 2020).

This result agrees with a study that reported that supplementation of Moringa at different levels in the dairy cow diet increases feed intake (Dong et al., 2019). Kholif et al. (2018) also reported a higher feed intake with Moringa diets than Berseem clover diet when fed to dairy goats. However, Mendieta-Araica et al. (2011) reported no differences in the feed intake among the treatments when Moringa leaf meal was fed to cows.

Protein supplementation has been shown to increase TDMI in diets with low-quality roughage (Patra, 2009), and this study shows that Moringa leaves supplementation has an additive effect on the intake of Rhodes grass hay, increasing its efficiency and utilization. The beneficial effect on feed intake and feed utilisation efficiency could have been mediated through enhanced rumen digestion and tissue metabolism.

4.3 *In vitro* Gas Production and Fermentation Characteristics

The result from this experiment shows that the *in vitro* gas production and fermentation characteristics of the diets and supplements varied widely, and it showed that Moringa had the least digestibility, evident from its low gas production. This can result from anti-nutritional factors inhibiting microbial degradation but simultaneously increasing the flow of undegradable nutrients, such as RUP, to the small intestine for enzymatic degradation. These results show that supplementation with Moringa will improve the proper utilization of the nutrients by increasing the ratio of rumen undegradable protein to the rumen degradable protein, which leads to improved feed utilisation efficiency. These results reflect those of Alarape et al., (2023) who also found that the Moringa supplemented treatments has low gas production.

Microbial fermentation of carbohydrates results in SCFA, which is used as the main energy source by ruminants, and it is estimated that they produce around 75% of the metabolizable energy required by cattle (Bergman, 1990). This result showed that Moringa produced high SCFA and low OMD despite its high ME, emphasizing its low susceptibility to microbial degradation in the rumen and increased flow of nutrients to the small intestine for enzymatic degradation. This also accords with our earlier observations, which showed that Moringa-supplemented treatments have high ME with low SCFA and OMD (Alarape et al., 2023).

It can therefore be concluded from this study that *Moringa oleifera* leaves fed at 10% of the total DM intake (4% of the body weight) can significantly improve the DM intake and the digestibility of dairy cows fed a basal diet of *Chloris gayana* hay in the tropics during dry season.

Declarations

5. Acknowledgements

This study was made possible with funding from TAGDev, a program under the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM).

6. Funding

Funding from Transforming African Agricultural Universities to Meaningfully Contribute to Africa's Growth & Development (TAGDev) program under the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) was greatly appreciated.

7. Data Availability

All datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

8. Authors Contributions

The study's inception and the methodologies were the authors' contributions. Perminus K. Migwi and James O. Ondiek supervised Omolara L. Alarape during data collection, data analysis and development of the manuscript. Omolara L. Alarape wrote the draft of the article, and it was read and approved by other authors.

9. Statement of Animal Rights

The materials and procedures used in this research were approved by Egerton University Research Ethics Committee, approval number EUISERC/APP/213/2023 and the National Commission of Science and Technology of Kenya under the license number NACOSTI/P/23/25204.

10. Conflict of Interest Statement

The authors report no potential conflict in the publication of this manuscript.

References

1. Alarape, O. L., Migwi, P. K. & Ondiek, J. O. (2023). Nutritional evaluation and *in vitro* dry matter digestibility (IVDMD) of *Moringa oleifera*, *Medicago sativa*, *Chloris gayana* and their combinations at different ratios. *International Journal of Veterinary Sciences and Animal Husbandry*, 8(4):232–237. <https://doi.org/10.22271/veterinary.2023.v8.i4d.602>
2. AOAC. (2005). Official method of Analysis. (18th ed). Association of Officiating Analytical Chemists, Washington DC. USA.
3. Bergman, E. N. (1990). Energy contributions of volatile fatty acids from the gastrointestinal tract in various species. *Physiological Reviews*. <https://doi.org/10.1152/physrev.1990.70.2.567>
4. Dong, L., Zhang, T., & Diao, Q. (2019). Effect of dietary supplementation of *Moringa oleifera* on the production performance and faecal methanogenic community of lactating dairy cows. *Animals*, 9(5), 262. <https://doi.org/10.3390/ani9050262>
5. Getachew, G., Makkar, H. P. S., & Becker, K. (2002). Tropical browses: contents of phenolic compounds, *in vitro* gas production and the stoichiometric relationship between short chain fatty acid and *in vitro* gas production. *The Journal of Agricultural Science*, 139(3), 341–352. <https://doi.org/10.1017/S0021859602002393>
6. Hao, X. Y., Gao, H., Wang, X. Y., Zhang, G. N., & Zhang, Y. G. (2017). Replacing alfalfa hay with dry corn gluten feed and Chinese wild rye grass: Effects on rumen fermentation, rumen microbial protein synthesis, and lactation performance in lactating dairy cows. *Journal of Dairy Science*, 100(4), 2672–2681. <https://doi.org/10.3168/jds.2016-11645>

7. KALRO. (2022). Kenya Agricultural and Livestock Research Organization <https://www.kalro.org>.
8. Kholif, A. E., Khatlab, H. M., El-Shewy, A. A., Salem, A. Z. M., Kholif, A. M., El-Sayed, M. M., & Mariezcurrena, M. D. (2014). Nutrient digestibility, ruminal fermentation activities, serum parameters and milk production and composition of lactating goats fed diets containing rice straw treated with *Pleurotus ostreatus*. *Asian-Australasian Journal of Animal Sciences*, 27(3), 357.
9. Kholif, A., Gouda, G., Olafadehan, O., & Abdo, M. (2018). Effects of replacement of *Moringa oleifera* for berseem clover in the diets of Nubian goats on feed utilisation, and milk yield, composition and fatty acid profile. *Animal*, 12(5), 964–972. <https://doi.org/10.1017/S1751731117002336>
10. Kholif, A., Morsy, T., Gouda, G., Anele, U., & Galyean, M. (2016). Effect of feeding diets with processed *Moringa oleifera* meal as protein source in lactating Anglo-Nubian goats. *Animal Feed Science and Technology*, 217, 45–55. <https://doi.org/10.1016/j.anifeedsci.2016.04.012>
11. Leng, R. A. (1990). Factors affecting the utilization of poor quality forages by ruminants particularly under tropical conditions. *Nutrition Research Reviews*, 44, 277–303.
12. Lodge-Ivey, S. L., Browne-Silva, J., & Horvath, M. B. (2009). Bacterial diversity and fermentation end products in rumen fluid samples collected via oral lavage or rumen cannula. *Journal of Animal Science*, 87(7), 2333–2337. <https://doi.org/10.2527/jas.2008-1472>
13. Mendieta-Araica, B., Spörndly, R., Reyes-Sánchez, N., & Spörndly, E. (2011). *Moringa (Moringa oleifera)* leaf meal as a source of protein in locally produced concentrates for dairy cows fed low protein diets in tropical areas. *Livestock Science*, 137, 10–17. <https://doi.org/10.1016/j.livsci.2010.09.021>
14. Menke, K.H., & Steingass, H. (1988). Estimation of energetic feed value from feed obtained from chemical analysis and *in vitro* gas production using rumen fluid. *Animal Research and Development*, 28, 7–55
15. Moyo, B., Patrick, J.M., & Muchenje, V. (2012). Effect of supplementing crossbred Xhosa lop-eared goat castrates with *Moringa oleifera* leaves on growth performance, carcass and non-carcass characteristics. *Tropical Animal Health and Production*, 44, 801–809. <https://doi.org/10.1007/s11250-011-9970-6>
16. Mutavi, S. K., Kanui, T. I., Njarui, D. M., Musimba, N. R. & Amwata, D. A. (2016). Innovativeness and Adaptations: The Way forward for Small scale Peri-Urban Dairy Farmers in semi-arid Regions of South Eastern Kenya. *International Journal of Scientific Research and Innovative Technology*. 3(5): 1–14.
17. Ørskov, E. R., & McDonald, I. (1979). The estimation of protein degradability in the rumen from incubation measurements weighed according to rate of passage. *Journal of Agricultural Sciences*, 92, 499–503. <https://doi.org/10.1017/S0021859600063048>
18. Palada, M. C., Chang, L., Yang, R., & Engle, L. M. (2007). Introduction and varietal screening of drumstick tree (*Moringa spp.*) for horticultural traits and adaptation in Taiwan. *International Conference on Indigenous Vegetables and Legumes. Prospectus for Fighting Poverty, Hunger and Malnutrition*, 752, 249–253. <https://doi.org/10.17660/ActaHortic.2007.752.40>.
19. Patra, A. K. (2009). Responses of intake, digestibility and nitrogen utilisation in goats fed low-quality roughages supplemented with tree foliage. *Journal of the Science of Food and Agriculture*, 89(9), 1462–1472.
20. Sánchez, N. R., Spörndly, E., & Ledin, I. (2006). Effect of feeding different levels of foliage of *Moringa oleifera* to creole dairy cows on intake, digestibility, milk production and composition. *Livestock Science*, 101(1–3), 24–31. <https://doi.org/10.1016/j.livprodsci.2005.09.010>
21. SAS. (2009). Statistical Analysis Systems. Version 9.2, SAS Inst., Inc., Cary, NC.
22. Silanikove, N. (2000). The physiological basis of adaptation in goats to harsh environments. *Small Ruminant Research*, 35, 181–193. [https://doi.org/10.1016/S0921-4488\(99\)00096-6](https://doi.org/10.1016/S0921-4488(99)00096-6)

23. Soliva, C. R., Kreuzer, M., Foidl, N., Foidl, G., Machmuller, A., & Hess, H.D. (2005). Feeding value of whole and extracted *Moringa oleifera* leaves for ruminants and their effects on ruminal fermentation *in vitro*. *Animal Feed Science and Technology*, 118, 47–62. <https://doi.org/10.1016/j.anifeedsci.2004.10.005>
24. Su, B., & Chen, X. (2020). Current Status and Potential of *Moringa oleifera* Leaf as an Alternative Protein Source for Animal Feeds. *Frontiers in Veterinary Science*, 7 (53). <https://doi.org/10.3389/fvets.2020.00053>
25. Tilley, J. M. A., & Terry, D. R. (1963). A two-stage technique for the *in vitro* digestion of forage crops. *Grass and Forage Science*, 18(2), 104–111.
26. Van Soest, P., Robertson, J., & Lewis, B. (1991). Methods for Dietary Fiber, Neutral Detergent Fiber, and Non-Starch Polysaccharides in Relation to Animal Nutrition. *Journal of Dairy Science*, 74(10), 3583–3597. [https://doi.org/10.3168/jds.S0022-0302\(91\)78551-2](https://doi.org/10.3168/jds.S0022-0302(91)78551-2)
27. Wambugu, S., Kiriimi, L., & Opiyo, J. (2011). Productivity trends and performance of dairy farming in Kenya. *Tropical Animal Health*, 9(12), 63–69. <http://41.89.96.81:8080/xmlui/handle/123456789/2323>
28. Wu, D., Cai, Z., Wei, Y., Zhang, C., Liang, G., & Guo, Q. (2013). Research advances in moringa as a new plant protein feed. *Chinese Journal of Animal Nutrition*, 25(3), 503–511.
29. Yameogo, C. W., Bengaly, M. D., Savadogo, A., Nikiema, P. A., & Traore, S. A. (2011). Determination of chemical composition and nutritional values *Moringa oleifera* leaves. *Pakistan Journal of Nutrition*, 10, 264–268.

Figures

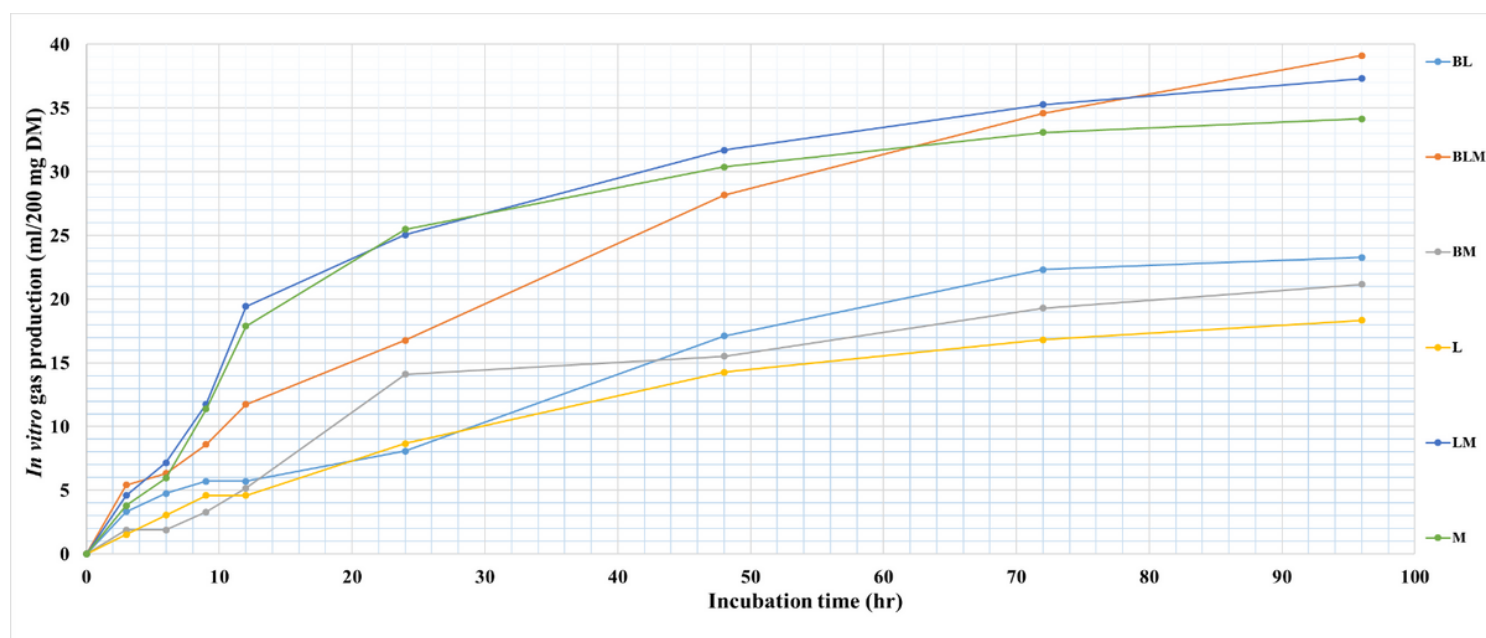


Figure 1

In vitro gas production of supplementing lactating Holstein-Friesian cows with different levels of Moringa leaves and Lucerne hay