Moringa oliefera leaf as potential, alternative protein source for livestock

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Journal of Livestock Science (ISSN online 2277-6214) 15: 141-149
Received on 29/2/24; Accepted on 15/4/24; Published on 25/4/24
doi. 10.33259/JLivestSci.2024.141-149

Abstract

The increased population of livestock has increased burden on use of conventional animal feed. Therefore, attempt has been made to use different unconventional feedstuff to reduce the dependency on conventional animal feed. *Moringa oleifera* is considered as one of most useful trees to use as feed supplements for animals as their leaves are highly nutritious, palatable and digestible with balanced chemical composition of protein and minerals. Moringa leaves are readily eaten by cattle, sheep, goats, pigs and rabbits. As new source of protein, *M. oleifera* has great potential to combat the feeding crisis. This review explores the possibilities of safe use of *M. oleifera* as a feed in different animal species, its nutrient content, digestion, and absorption characteristics, and its feeding effects.

Keywords: Alternative protein sources; *Moringa oliefera*; Plant secondary metabolites

Introduction

India possesses the highest livestock population in the world. According to the 20th livestock census, the total Livestock population is 535.78 million in the country showing an increase of 4.6% over previous census. Though India has a huge livestock population yet the production of milk per animal and other livestock products is very low compared to other country. The main reason for the low productivity of our farm animals is the feeding of poor quality feeds and fodders to animal due to feed shortage along with the low genetic potential of the animals (Sharma et al., 2021).

The need to introduce locally available, cheap alternative feeds and fodders has become imperative to overcome nutritional crisis and to ensure optimum production of livestock throughout out the year. There has been an increase in the use of plant leaf meals in animal diets since protein from leaf sources is likely the most naturally available and affordable source of protein (Amata, 2014).

Moringa tree (*Moringa oliefera),* is a fast growing, hardy tree native to Indian sub continents. Some common name of moringa includes "drumstick tree", "horseradish tree" and Sajina (local name in Assam). Moringa belongs to the Moringaceae family. The family consists of the single genus Moringa and the botanical name of the tree is *Moringa oleifera.* It is grown all over the tropics for its multipurpose use viz. human food, livestock feeds, medicinal values, water purification etc. *Moringa oleifera*, also known as the "miracle tree" due to its immense medicinal and nutritional benefits. It is very widely adaptable, drought tolerant and can withstand diverse temperature range, soil types and has very fast growth. It has been reported to be used as animal feed/ fodder besides being used for human consumption. As *M. oleifera* leaves have noticeably higher quantities of crude protein, vitamins, and minerals, and little to no anti-nutritional factor compared to other leafy vegetables or fodders, they can be utilized as livestock feed (Bukola Babatunde, 2016). Dry *M. oliefera* leaves contain 28% CP, 6.23% EE, 15.39% CF, 41.95% NFE and 8.43% ash (Elaidy et al., 2017). In this context, the present review study is conducted to assess the potential of *M. oliefera* as alternative protein sources for livestock.

Cultivation of Moringa

The southern Indian states of Tamil Nadu, Andhra Pradesh, Karnataka, and Kerala are the main locations for moringa cultivation. Two methods are used to propagate moringa: direct field sowing of the seeds and transplantation of cuttings and seedlings. For a very long time, cultivating primarily perennial varieties has been known. July to October is the ideal time of year to grow moringa. At a maximum depth of 2 cm, seeds germinate in a span of two weeks. When seedlings are scheduled in nursery, they can be transplanted 3-6 weeks following germination or at a height of approximately 30 cm (Ojiako et al., 2011). Each acre needs 25 kg of seeds. Cutting is preferable, when labor or seed availability is not a constraint.

An exact replica of the mother tree is expected when cuttings are used rather than seeds. Additionally, cuttings often grow more quickly, starts blooming within eight months. According to Ramachandran et al. (1980), plants grown from seeds yield lower-quality fruits. However, Animashaun et al. (2013) propose that trees grown from seeds have longer roots than trees grown from cuttings, which is advantageous for stabilization and water access. Depending on growth, the leaves can be harvested six to twelve months after planting. This crop yields between 50 and 55 tons of pods per hectare.

Nutrient composition of *Moringa oliefera*

Dry *M. oliefera* leaves (DMOL) contains 28% CP, 6.23% EE, 15.39% CF, 41.95% NFE and 8.43% ash (Elaidy et al., 2017). According to Moyo et al., (2011), the dried leaf of *M. oliefera* has crude protein levels of 30.3% and 19 amino acids. They listed the mineral composition as 3.65% calcium, 0.3% phoshorus, 0.5% magnesium, 1.5% potassium, 0.164% sodium, 0.63% sulphur, 8.25% copper, 13.03 mg/kg zinc, 86.8 mg/kg manganese, 490 mg/kg iron and 363 mg/kg selenium. The neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL) and acid detergent cellulose (ADC) were 11.4, 8.49, 1.8 and 4.01 percent respectively. They reported that the dried leaves of *M. oliefera* contain around 3.2% the condensed tannins and 2.02% total polyphenols.

Plant secondary metabolites and bioactive compounds

The young forages (leaves plus stems) of *M. oleifera* have moderate amounts of secondary metabolites and bioactive compounds with pharmacological or nutraceutical and growth promoting properties, which are concentrated in the leaves, petioles and to a lesser extent in the stems(Valdivie et al., 2020). However, the amount of antinutrients in *M. oleifera* leaf fluctuates depending on the genetic make-up of the plant, including the cultivation and growing conditions (Sultana et al., 2014). For instance, the content of tannins present in Moringa leaves ranges from 12.0 to 20.6 mg/g (Ferreira et al., 2008). Although an M. oleifera leaves contains saponins, which give it a bitter flavor, they are only present as 4.7–5 g/kg of dry matter content. This quantity cannot cause any adverse effects on livestock (Moyo et al., 2011). Another detrimental antinutrient that is frequently present in tree leaf forages is lignin. The adverse effects of lignin in Moringa leaf meal has not been studied, but *M. oleifera* leaves have relatively low fiber contents (5.9%in dry matter) (Su and Chen, 2020). At this percentage, adverse effects from lignin are negligible. Notably, lignin content in tree leaves tends to increase with growth time. Lignin accumulation in M. oleifera leaves can be prevented by shortening the cutting interval and harvesting young leaves during the early vegetative period. Additionally, *M. oleifera* leaves have lower phytate and oxalate concentrations than other common vegetables (Shih et al., 2011). Only 22.3 mg/g in dry matter of phytates can be found in *M. oleifera* leaf (Stevens et al., 2015). In a similar way, the amount of oxalate in spinach leaf is 125.7 mg/g, while that in green amaranth leaf is 100.5 mg/g (Radek and Savage, 2008). The concentration of antinutritional factors of the *M. oleifera* (leaves plus stems) does not cause damage. In reality, it is not necessary to completely remove the antinutritional components from *M. oleifera* leaves because including small amounts of these components in animal feed not only helps to improve the quality of the meat but also lowers methane emission from ruminants (Su and Chen, 2020).

Effect of feeding Moringa leaf meal in ruminant performance

The growing human population has increased the demand for meat products worldwide. In addition to providing high-quality proteins for human, ruminants are significant source of greenhouse gas emissions. Each year, approximately 100 million tons of methane is released by cattle (Gerber et al., 2013). Reducing the intensity of emissions can stop significant increases in the total amount of CH_4 emissions from ruminants. The control of amount of CH_4 produced is mostly dependent on the composition of animal feed. In the ruminant stomachs, methanogenic microbes (which are members of the Archaea) produce methane. In order to remove or significantly lessen the activity of the methanogenic microbes in the gut, animal feed has recently been supplemented with biological and chemical CH_4 inhibitors as part of ruminant CH_4 reduction efforts (Haque, 2018). Because *M. oleifera* leaves are potent natural methanogen inhibitors, they are being explored as a substitute for important antibiotic feed additives that alternates ruminal fermentation pathways (Soliva et al., 2005). Dong et al. (2019) added *M. oleifera* leaves to the diet to observe its effect on the fecal methanogenic community and production performance in nursing cows. They observed that *M. oleifera* altered the diversity and composition of methanogens as well as the improved fat content in the milk. *Methanobrevibacter sp*. was found to be the predominant archaeal species in the fecal community in the control treatment. In comparison to the control group, the abundance of *Methanobrevibacter ruminantium* dropped when *M. oleifera* was introduced to the diet, while *Methanosphaera* and *Methanosphaera sp*. rose. Therefore, *M. oleifera* may lower CH_4 emissions by changing the microbiomes in the rumen. Soliva et al. (2005) reported that *M. oleifera* may lower CH_4 emissions. When *M. oleifera* leaves were fully extracted from the diet, they found a 17% reduction in daily methane output as opposed to diets that contained soybean or rapeseed meal. A different in vitro investigation also suggested that substituting *M. oleifera* leaf meal for soybean meal may cut CH_4 emissions by as much as 50% (Elghandour et al., 2017). In a similar way, Parra-Garcia et al. (2019) carried out an in vitro study on dietary corn grain using *M. oleifera* leaf extracts to assess the impact on ruminal fermentation. They discovered that high concentrations of *M. oleifera* extract delayed the start of CH_4 production, which in turn reduced the production of CH_4, CO_2, and total biogas. This outcome is consistent with the findings of Dey et al. (2014), who were able to lower the methane level and raise the organic matter's degradability in vitro by supplementing buffalo diet with wheat straw that included *M. oleifera* leaves. These effects could be connected to the tannins or saponins found in Moringa leaves.

Using live yeast cultures (Saccharomyces cerevisiae) and *M. oleifera* extracts as feed supplements, Pedraza-Hernández et al. (2019) offered a novel and intriguing technique to investigate the sustainable reduction of CH_4 emissions from goats. With a low emission rate of 11.7% after 72 hours of incubation, this study demonstrated the great efficacy of combining *M. oleifera* extract and *S. cerevisiae* in the diet to inhibit the generation of methane. Furthermore, the interaction between *S. cerevisiae* and *M. oleifera* extract considerably reduced the proportionate CO_2 production during 8, 24, 48, and 72 hours of incubation. This study is partially in accordance with the findings of Polyorach et al. (2014), which indicated that dose-dependent supplementing causes growth performance and CH_4 emission to rise and decrease, respectively. As a result, *M. oleifera* leaves may be added to ruminant diets as a useful natural feed supplement to decrease CH_4 generation and improve ruminal nutrient utilization efficiency.

Since ruminant can digest cellulose, lignin, and other secondary metabolites due to their rumen structures, they can also digest forages from tree, such as *M. oleifera*. Supplementation of 25, 50, 75 and 100% *M. oleifera* leaf meal in daily diets of ram as replacement for cotton seed meals did not alter body weight gain relative to the body weight gain in the control group (Adegun and Aye, 2013). Similarly, Manh et al. (2005) leaves did not observe difference in feed intake, ruminating rate, and digestibility in goats fed with *M. oleifera* leaves compared with those with *Leucaena leucocephala*. Increase in live weight gain, and digestibility of dry matter, crude protein, neutral detergent fiber, and organic matter in goats was observed by Aregheore, (2002) when fresh *M. oleifera* leaves were fed at 20 and 50% as replacement for batiki grass incomparison to to control. Kholif et al. (2016) illustrated that feed intakes and body weight changes showed improvement when the

Panicum maximum diet was supplemented with *M. oleifera* leaf mealdiets. Kholif et al. (2019) also reported that supplementing diets of Nubian does with *M. oleifera* extract enhanced milk yield by about 6% and energy-corrected milk yield by 12%. *M. oleifera* extract decreased milk individual and total saturated fatty acids by about 4.6–5.6%, and increased individual and total unsaturated fatty acids by about 11.5–13.9%. Similarly, increase in total conjugated linoleic acid by about 17.4–23.2% was also noticed. Dietary inclusion of *M. oleifera* significantly decreased the concentrations of serum triglycerides and cholesterol but increased ($p < 0.05$) the concentration of serum glucose in lactating goats (Kholif et al., 2016). Fadiyimu et al. (2010) reported that feeding of *Panicum maximum* meal with 25% *M. oleifera* leaves supplements led to higher crude protein intake, dry matter and nutrient digestibility, nitrogen retention, and hematological profile gain in West African dwarf sheep. As per the report of Kholif et al. (2018) replacement of 75% dry matter of berseem clover with *M. oleifera* leaf can improve utilization of feed in Nubian goats. Moringa diets also increased serum total protein, albumin, and glucose levels but decreased cholesterol and triglyceride levels. It has been observed that supplementation of *M. oleifera* leaf meal improves not only growth performance but also milk output and the quality of cows and goats (Kholif et al., 2019; Babiker et al., 2017; Sanchez et al., 2006). According to Kholif et al. (2018), supplementation with *M. oleifera* leaf to replace 75% dry matter of berseem clover can improve feed utilization in Nubian goats. They also observed that Moringa diets increased serum total protein, albumin, and glucose levels but decreased cholesterol and triglyceride levels. This study demonstrated that dietary supplementation with Moringa leaves is a potential strategy to improve meat quality. Moreover, *M. oleifera* leaf extract is a powerful ingredient for increasing feed intake, and the digestibility of dry matter, organic matter, and neutral detergent fiber and does not affect the digestibility of crude protein in Nubian goats (Kholif et al., 2019). As a nutrient source supplement to forage, *M. oleifera* leaf meal improves not only growth performance but also milk output and the quality of cows and goats (Kholif *et al*., 2019; Babiker *et al*., 2017; Sanchez *et al*., 2006).

Shankhpal et al. (2019) studied the effect of feeding Moringa (*Moringa oleifera*) as green fodder on feed intake, milk yield, microbial protein synthesis, and blood profile, a study was conducted on twenty lactating crossbred cows and found improvement in milk yield, and milk fat; improved carotene content in milk, increased intestinal flow of microbial nitrogen and thus improving net daily income of dairy farmers. Abdel-Raheem and Hasan (2021) found that dietary supplementation of 15% Moringa leaf meal improved rumen fermentation, growth performance, blood metabolites, plasma IGF-I and mitigated ammonia and methane without any adverse effects in growing buffalo calves. El-Badawi et al. (2023) reported that 50 g *M. olifera* leaves powder supplementation to the diets of milking buffaloes improved milk yield, milk composition, nutrients digestibility, nutritive value and total antioxidant capacity. Zeng et al. (2017) illustrated that The partial replacement of alfalfa hay (≤50%) and maize silage with *M. oleifera* silage had no negative effects on milk yield, in vivo nutrient apparent digestibility and serum biochemical profiles of lactating cows. *M. oleifera* leaves can therefore be utilized as an alternate source of protein for animal nutrition, particularly for ruminants. Bashar et al. (2020) reported significantly higher milk yields , better feed efficiency, increased concentration of total volatile fatty acid and decreased blood and milk cholesterol, and ammonia-nitrogen (NH_3-N) in lactating cows fed on moringa feed without showing any significant ($p > 0.05$) change in CH_4 production, fat, solid not fat, lactose or protein content of milk.

Effect of feeding Moringa leaf meal in non ruminant performance

It has been observed that feeding of *M. oleifera* leaf meal is effective in improve bowel health by balancing intestinal microflora, thus promoting weight gain (Ferreira et al., 2019; Nkukwana et al., 2014). Alabi et al. (2017) observed higher body weights, low total feed intake, and improved feed conversion ratio in broilers whose diet was supplemented with *M. oleifera* leaf extracts. These results might be attributed to presence of bioactive components, which improve nutrient utilization in Moringa leaf extracts. The benefits of dietary supplementation with *M. oleifera* leaf meal in commercial broiler chickens were studied by Rao et al. (2018). They observed adding *M. oleifera* leaf meal (500 and 1,000 mg/kg) to the diet of 42-day-old commercial broiler chickens boosted humoral immune response and decreased lipid peroxidation in the liver without having any detrimental impacts on performance or carcass qualities. On the other hand, Onunkwo and George (2015) found no significant differences in broiler chickens' feed intake and body growth weight when fed soybean meal with *M. oleifera* leaf at the rates of 0.0, 5.0, 7.5, and 10%, demonstrating that *M. oleifera* leaf meal can replace a portion of the protein source in poultry diets without having a negative impact on growth performance. Similar findings were made by Ayssiwede et al. (2011), who found that adding up to 24% of *M. oleifera* leaf to groundnut cake meal had no negative effects on the characteristics of Senegal chicken's average daily gain, feed conversion ratio, total weight gain, mortality, carcass, or organs. The most financially successful diets for chickens were those containing 8 and 16% *M. oleifera* leaf, which significantly accelerated their growth rates.

Positive effect of inclusion of *M. oleifera* leaf meal in layer diet for improvement performance and egg quality of has been reported. Olugbemi et al. (2010) observed that in commercial egg strain chickens, the egg production was not affected on addition of 5 and 10% *M. oleifera* leaves into cassava-chip-based diets. Similarly, increase in egg weight was reported by Kakengi et al. (2007) on replacement of 15 or 20% sunflower seed meal with *M. oleifera* leaf powder.

M. *oleifera* leaf meal has been reported to be improve pork quality. Abdel-Azeem et al. (2017) described that finisher pigs fed with meal containing up to 5% *M. oleifera* leaf did not show any negative effect on feed conversion ratio and carcass traits (e.g., cutability and backfat thickness) and even developed a strong acceptable odor and a striking dark red color in meat that has been refrigerated for long time. Pigs fed containing more than 5% *M. oleifera* leaf meal had higher daily feed intake but their feed conversion ratio were poorer than pigs fed 0, 2.5, and 5% *M. oleifera* leaf meal (Mukumbo et al., 2014). However, Dany et al. (2016) found no growth-related effects from feeding up to 40% *M. oleifera* leaf to Mexican hairless pigs. Unsaturated fatty acids, which are beneficial to consumer health, were found in greater quantities in meat and subcutaneous fat due to consumption of *M. oleifera* leaf meal. Similar results were reported by Acda et al. (2010), who did not observe any effect on average daily gains when Commercial pre-starter and starter pigs were fed with 10% *M. oleifera* leaf. Barman et al. (2020) studied the effects of replacing groundnut cake (5%,10%) with dried *M. oleifera* leaves on growth and nutrient utilization in crossbred (Hampshire × Ghungroo) grower pigs and reported that the average body weight gain (g/day) was higher ($P>0.05$) in Moringa leaves supplemented groups though the average dry matter intake was not significantly affected. Barman and Rai (2008) and Khan *et al*. (2014) reported reduced dry matter intake in pigs by decreasing the palatability of diet due to presence of tannin in moringa. The digestibility coefficients (%) of dry matter, organic matter, ether extract, crude fibre and nitrogen free extracts was increased ($P>0.05$) while the digestibility of crude protein was increased ($P<0.05$) in pigs fed with Moringa leaves supplemented ration (Barman *et al*., 2020). Mukumbo et al. (2014) reported that 5% Moringa leaf meal can be included in the finisher pig ration without any adverse effect on feed conversion ratio, carcass and meat quality, and it improves the storage life of pork.

Effect of feeding Moringa leaf meal on performance of the aquatic animals:

M. oleifera leaves work well as aquafeed in aquaculture.According to a number of researches (Ozovehe, 2012; Sherif et al. 2014), moringa can greatly improve the growth indices and feed consumption of fish. These encouraging outcomes could be explained by the fact that moringa enhances growth indices since it is a good source of lipids, proteins, and crude fibers (Francis et al., 2001). According to Safrida et al. (2020), adding powdered moringa leaves (*Moringa oleifera*) to fish diet can boost growth rate and support health of Tambaqui (Colossoma macropomum). Mansour et al. (2018) assessed effect of feeding increased level *M. oliefera* leaf on immune system and growth of seabream. They observed that fish samples fed with 5 and 10% *M. oliefera* leaves had higher intestinal mucosal immunity genes and growth performance. However, the growth performance and feed utilization were reduced when the inclusion level of *M. oliefera* leaf was increased to up to 15%. Therefore, they recommended that *M. oleifera* leaf should be included at a 10% level in seabream diet.

Strategies for future use of *Moringa oleifera*

Despite the widespread use of *M. oleifera* leaves to feed a variety of animals, there are still several issues that must be resolved before large-scale feed production can begin. One of the main limiting variables is the existence of endogenous antinutrients in plant leaf meals. Therefore, large amounts of *M. oleifera* leaf inclusion in meals have a detrimental effect on the growth performance of animals. The primary antinutrients found in *M. oleifera* leaves are tannins, phytic acid, and saponin (Shi et al. 2018). The biological value and acceptance of *M. oleifera* leaf as a regular food source can be limited by antinutrients, which generally diminish palatability, protein digestibility, and mineral bioavailability. For this reason, the leaves need to be properly treated before being consumed in big quantities.The leaves of *M. oleifera* should not be supplied raw to animal, it should to be treated to reduce antinutrients (Shi et al. 2018). There are several methods for reducing antinutrients' detrimental effects and raising the nutritional value of tree foliage. Antinutrients can be reduced or eliminated by physical, chemical, or biological techniques; these techniques include soaking, cooking, fermenting, irradiating, and applying an enzyme treatment. The phytate concentration of *M. oleifera* leaves can be greatly decreased by the majority of physical techniques, including cooking and soaking (Vitti et al. 2005; Mbah et al. 2012; Chanchay and Poosaran, 2009). Minerals are among the dietary components that are lost during treatment, though. As a result, substituting this method for another or combining it with another one will help lower the amount of antinutrients in *M. oleifera* leaves. Fermentation is by far the most effective and nutritionally beneficial process method, which makes feed digestible, nutritious, and palatable.. Fermentation generally has a positive effect on the availability of iron and other minerals in leaves and can lower the levels of several antinutrients, especially phytates, lignin, and cellulose. Fermentation raises the amount of digestible protein in *M. oleifera* while reducing the phytate level by 66.9% (Thierry et al. 2013; Wang et al. 2018). Fermentation lowers the levels of trypsin, protease, and tannin in other plant foods (Ali et al. 2019; Diouf et al. 2019). In comparison to soaking, fermentation is more efficient in reduction of antinutrients. Hence, the use of fermentation for the treatment of *M. oleifera* leaves would be advantageous from nutritional point.

Conclusion

The wonder tree *Moringa oleifera* have much potentiality to be used as alternative protein source in livestock. In order to get full utilization of the potential benefits of *M. oleifera* plant as a livestock feed, more researches in these contexts are required. As a conclusion, more attention need to be paid to the usage of *M. oleifera* as nutritional feed resources in livestock in a large scale in countries like India and other countries where the *M. oleifera* tree can be grown to produce more natural as environmental friendly materials.

Conflict of interest: Authors do not have conflict of interest in this study.

References

1) Abdel-Azeem, A.F., Mohamed, F.A., El-Shiekh, S.E.M. and Hessin A.F. 2017. Maximizing productivity of lohmann chickens by feeding diets inclusion different levels of *Moringa oleifera* leaf powder as a safe feed additive. Journal of Animal and Poultry Production, 8(8), 319-328. doi: 10.21608/JAPPMU.2017.45989

2) Abdel-Raheem, S.M. and Hassan, E.H. 2021. Effects of dietary inclusion of *Moringa oleifera* leaf meal on nutrient digestibility, rumen fermentation, ruminal enzyme activities and growth performance of buffalo calves. Saudi Journal of Biological Sciences, 28(8), 4430-4436. doi: 10.1016/j.sjbs.2021.04.037

3) Acda, S.P., Musilunga, H.G.D. and Moog, B.A. 2010. Partial substitution of commercial swine feeds with Malungay (*Moringaoleifera*) leaf meal under backyard conditions. Philippine Journal of Veterinary and Animal Sciences, 36(2), 137–146.

4) Adegun, M.K. and Aye, P.A. 2013. Growth performance and economic analysis of West African Dwarf Rams fed *Moringa oleifera* and cotton seed cake as protein supplements to *Panicum Maximum.* American Journal of Food and Nutrition, 3, 58–6. doi: 10.5251/ajfn.2013.3.2.58.63

5) Alabi, O.J., Malik, A.D., Ngambi, J.W., Obaje, P. and Ojo, B.K. 2017. Effect of aqueous *Moringa oleifera* (Lam) leaf extracts on growth performance and carcass characteristics of Hubbard broiler chicken. Brazilian Journal of Poultry Science, 19(2), 273-280. doi: 10.1590/1806-9061-2016-0373

6) Ali, S., Saha, S., Kaviraj, A. 2019. Fermented mulberry leaf meal as fishmeal replacer in the formulation of feed for carp *Labeo rohita* and catfish *Heteropneustes fossilis*—optimization by mathematical programming. Tropical Animal Health and Production, 2, 1–11. doi: 10.1007/s11250-019-02075-x

7) Amata, I.A. 2014. The use of non-conventional feeding resources (NCFR) for livestock feeding in the tropics: A review. Journal of Global Bioscience, 3(2), 604-613.

8) Animashaun, J. 2013. Prospects of Agriculture Enterprise for Sustainable Economic Development: Success Story of University of Ilorin Moringa Value-Addition Activities. Proceedings of the 4th International Conference of the African Association of Agricultural Economists, Hammamet, Tunisia, 22–25 September 2013.

9) Aregheore, E.M. 2002. Intake and digestibility of *Moringa oleifera*–batiki grass mixtures by growing goats. Small Ruminant Research, 46(1), 23-2. doi: 10.1016/S0921-4488(02)00178-5

10) Ayssiwede, S.B. Dieng, A., Bello, H., Chrysostome, C.A.A.M., Hane, M.B. et al. 2011. Effects of *Moringa oleifera* (Lam.) leaves meal incorporation in diets on growth performances, carcass characteristics and economics results of growing indigenous senegal chickens. Pakistan Journal of Nutrition, 10(12), 1132-1145. doi: 10.3923/pjn.2011.1132.1145

11) Babiker, E.E., Juhaimi, F.A., Ghafoor, K. and Abdoun, K.A. 2017. Comparative study on feeding value of Moringa leaves as partial replacement for alfalfa hay in ewes and goats. Livestock Science, 195, 21-26. doi: 10.1016/j.livsci.2016.11.010

12) Barman, K. and Rai, S.N. 2008. Utilization of tanniniferous feeds: 5. Effect of supplemntation of *Acacia nilotica* pods on production performance of crossbred cows. Indian Journal of Animal Science, 78(2), 197–202.

13) Barman, K., Banik, S., Thomas, R., Kumar, S., Das, A.K. et al. 2020. Effect of replacing groundnut cake with dried *Moringa oleifera* leaves on growth and nutrient utilization in crossbred (Hampshire× Ghungroo) grower pigs. Indian Journal Animal Science, 90(8), 1155–1158.

14) Bashar, M.K., Huque, K.S., Sarker. N. S. and Sultana, N. 2020. Quality assessment and feeding impact of Moringa feed on intake, digestibility, enteric CH4 emission, rumen fermentation, and milk yield. Journal of Advanced Veterinary and Animal Research, 7(3), 521–529.

15) Bukola Babatunde 2016. A systemic review of studies investigating *Moringa oleifera* leaf meal as a feed for livestock, Journal of Fisheries & Livestock Production, 4, 2. doi: 10.4172/2332-2608.C1.006

16) Chanchay, N. and Poosaran, N. 2009. The reduction of mimosine and tannin contents in leaves of *Leucaena leucocephala*. Asian Journal of Food and Agro-Industry, 2, S137–S144.

18) Dany, D.C., Jorge, O.O., Ángel, S.V., Enrique, S.D., Valentin, P.R. et al. 2016. Effect of *Moringa oleifera* meal inclusion on meat quality from the Mexican hairless pig. ARPN Journal of Agricultural and Biological Science, 11(4), 131-141.
19) Dey, A., Paul, S.S., Pandey, P., Rathore, R. 2014. Potential of *Moringa oleifera* leaves in modulating in vitro methanogenesis and fermentation of wheat straw in buffalo. Indian Journal of Animal Science, 84, 533–538.
20) Diouf, A., Sarr, F., Sene, B., Ndiaye, C., Fall, S.M., Ayessou, N.C. 2019. Pathways for reducing anti-nutritional factors: prospects for *Vigna unguiculata*. Journal of Nutritional Health & Food Science, 2, 1–10.
21) Dong, L.F., Zhang, T.T., Diao, Q.Y. 2019. Effect of dietary supplementation of *Moringa oleifera* on the production performance and fecal methanogenic community of lactating dairy cows. Animals, 9, 262. doi: 10.3390/ani9050262
22) Elaidy, A.A., AbouSelim, I.A., Abou-Elenin, E.I., Abbas, M.S. and Sobhy, H.M. 2017. Effect of Feeding Dry *Moringa oleifera* Leaves on the Performance of Suckling Buffalo Calves, Asian Journal of Animal Science, 11(1), 32-39. doi: 10.3923/ajas.2017.32.39
23) El-Badawi, A.E.Y., Hassan, A.A., Khalel, M.S., Yacout, M.H. and El Naggar, S. 2023. Effect of *Moringa oleifera* leaves powder in diets of lactating buffaloes. Bulletin of the National Research Centre, 47(1), 4. doi: https://doi.org/10.1186/s42269-022-00977-9
24) Elghandour, M.M.Y., Vallejo, L.H., Salem, A.Z.M., Mellado, M., Camacho, L.M. et al. 2017. *Moringa oleifera* leaf meal as an environmental friendly protein source for ruminants: biomethane and carbon dioxide production, and fermentation characteristics. Journal of Cleaner Production, 165, 1229–1238. doi: 10.1016/j.jclepro.2017.07.151
25) Fadiyimu, A.A., Alokan, J.A. and Fajemisin, A.N. 2010. Digestibility, nitrogen balance and haematological profile of West African dwarf sheep fed dietary levels of *Moringa oleifera* as supplement to Panicum maximum. Journal of American Science, 6(10), 634-643.
26) Ferreira, F.N.A., Ferreira, W.M., da Silva Inacio, D.F., Neta, C.S.S., das Neves Mota, K.C. et al. 2019. In vitro digestion and fermentation characteristics of tropical ingredients, co-products and by-products with potential use in diets for rabbits. Animal Feed Science and Technology, 252, 1-10. doi:10.1016/j.anifeedsci.2019.03.011
27) Ferreira, P.M.P., Farias, D.F., Oliveira, J.T.D.A. and Carvalho, A.D.F.U. 2008. *Moringa oleifera*: bioactive compounds and nutritional potential. Revista de Nutriçao, 21(4), 431-437. doi: 10.1590/S1415-52732008000400007
28) Francis, G., Makkar, H.P.S. and Becker, K. 2001. Antinutritional factors present in plant derived alternate fish feed ingredients and their effects in fish. Aquaculture, 199,197–227.
29) Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C. Et al. 2013. Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and agriculture Organization of the United Nations (FAO).
30) Haque, M.N. 2018. Dietary manipulation: a sustainable way to mitigate methane emissions from ruminants. Journal of Animal Science and Technology, 60, 15. doi: 10.1186/s40781-018-0175-7
31) Kakengi, A.M.V., Kaijage, J.T., Sarwatt, S.V., Mutayoba, S.K., Shem, M.N. et al. 2007. Effect of *Moringa oleifera* leaf meal as a substitute for sunflower seed meal on performance of laying hens in Tanzania. Livestock Research for Rural Development, 19 (8), 120. doi: http://www.lrrd.org/lrrd19/8/kake19120.htm
32) Khan, N., Rastogi, A., Barman, K., Sharma, R.K. and Bashir, Y. 2014. Effect of feeding mixed silage of oat fodder and jamun leaves on nutrient utilization in goats. Indian Journal of Animal Science, 84(1), 85-87. doi: 10.56093/ijans.v84i1.37334
33) Kholif, A.E., Gouda, G.A., Galyean, M.L., Anele, U.Y. and Morsy, T.A. 2019. Extract of *Moringa oleifera* leaves increases milk production and enhances milk fatty acid profile of Nubian goats. Agroforestry Systems, 93, 1877-86. doi: 10.1007/s10457-018-0292-9
34) Kholif, A.E., Gouda, G.A., Olafadehan, O.A. and Abdo, M.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. doi: 10.1017/S1751731117002336
35) Kholif, A.E., Morsy, T.A., Gouda, G.A., Anele, U.Y. and Galyean, M.L. 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. doi: 10.1016/j.anifeedsci.2016.04.012
36) Manh, L.H., Dung, N.N.X. and Ngoi, T.P. 2005. Introduction and evaluation of *Moringa oleifera* for biomass production and as feed for goats in the Mekong Delta. Livestock Research for Rural Development, 17(9), 138-143. doi: http://www.lrrd.org/lrrd17/9/manh17104.htm

37) Mansour, A.T., Miao, L., Espinosa, C., Garcia-Beltran, J.M., Francisco, D.C.C., Esteban, M.A. 2018. Effects of dietary inclusion of *Moringa oleifera* leaves on growth and some systemic and mucosal immune parameters of seabream. Fish Physiology and Biochemistry, 44, 1223–40. doi: 10.1007/s10695-018-0515-z
38) Mbah, B.O., Eme, P.E., Paul, A.E. 2012. Effect of drying techniques on the proximate and other nutrient composition of *Moringa oleifera* leaves from two areas in Eastern Nigeria. Pakistan Journal of Nutrition, 11, 1044–1048. doi: 10.3923/pjn.2012.1044.1048
39) Moyo, B., Masika, P.J., Hugo, A. and Muchenje, V. 2011. Nutritional characterization of Moringa (*Moringa oleifera* Lam.) leaves. African Journal of Biotechnology, 10(60), 12925-12933. doi: 10.5897/AJB10.1599
40) Mukumbo, F.E., Maphosa, V., Hugo, A., Nkukwana, T.T., Mabusela, T.P. et al. 2014. Effect of *Moringa oleifera* leaf meal on finisher pig growth performance, meat quality, shelf life and fatty acid composition of pork. South African Journal of Animal Science, 44(4), 388-400. doi: 10.4314/sajas.v44i4.9
41) Neutelings, G. 2011. Lignin variability in plant cell walls: contribution of new models. Plant Science, 181(4), 379-386. doi: 10.1016/j.plantsci.2011.06.012
42) Nkukwana, T.T., Muchenje, V., Pieterse, E., Masika, P.J., Mabusela, T.P. et al. 2014. Effect of *Moringa oleifera* leaf meal on growth performance, apparent digestibility, digestive organ size and carcass yield in broiler chickens. Livestock Science, 61, 139-146. doi: 10.1016/j.livsci.2014.01.001
43) Ojiako, F.O., Adikuru N.C. and Emenyonu C.A. 2011. Critical issues in Investment, Production and Marketing of *Moringa oleifera* as an Industrial Agricultural raw material in Nigeria. The Journal of Agricultural Research and Development, 10, 39–56.
44) Olugbemi, T.S., Mutayoba, S.K. and Lekule, F.P. 2010. Evaluation of *Moringa oleifera* leaf meal inclusion in cassava chip based diets fed to laying birds. Livestock Research for Rural Development, 22, 6. doi: http://www.lrrd.org/lrrd22/6/olug22118.htm
45) Onunkwo, D.N. and George, O.S. 2015. Effects of *Moringa oleifera* leaf meal on the growth performance and carcass characteristics of broiler birds. IOSR Journal of Agriculture And Veterinary Science, 8(3), 63-66. doi: 10.9790/2380-08326366
46) Ozovehe, B.N. 2012. Growth performance, haematological indices and some biochemical enzymes of juveniles *Clarias gariepinus* (Burchell 1822) fed varying levels of *Moringa oleifera* leaf meal diet. Journal of Aquaculture Research & Development, 04, 166-172.
47) Parra-Garcia, A., Elghandour, M.M.M.Y., Greiner, R., Barbabosa-Pliego, A., Camacho-Diaz, L.M., et al. 2019. Effects of *Moringa oleifera* leaf extract on ruminal methane and carbon dioxide production and fermentation kinetics in a steer model. Environmental Science and Pollution Research, 26, 15333–15344. doi: 10.1007/s11356-019-04963-z
48) Pedraza-Hernandez, J., Elghandour, M.M.M.Y., Khusro, A., Camacho-Diaz, L.M., Vallejo, L.H., Barbabosa-Pliego, A. et al. 2019. Mitigation of ruminal biogases production from goats using *Moringa oleifera* extract and live yeast culture for a cleaner agriculture environment. Journal of Cleaner Production, 234, 779–786. doi: 10.1016/j.jclepro.2019.06.126
49) Polyorach, S., Wanapat, M., Cherdthong, A. 2014. Influence of yeast fermented cassava chip protein (YEFECAP) and roughage to concentrate ratio on ruminal fermentation and microorganisms using in vitro gas production technique. Journal of Animal Science, 27, 36–45. doi: 10.5713/ajas.2013.13298
50) Radek, M. and Savage, G.P. 2008. Oxalates in some Indian green leafy vegetables. International Journal of Food Sciences and Nutrition, 59(3), 246-260. doi: 10.1080/09637480701791176
51) Ramachandran, C., Peter, K.V. and Gopalakrishnan P.K. 1980. Drumstick (*Moringa oleifera*): A multipurpose Indian vegetable. Economic Botany, 34, 276–283. doi: 10.1007/BF02858648.
52) Rao, S.V.R., Raju, M.V.L.N., Prakash, B., Rajkumar, U. and Reddy, E.P.K. 2018. Effect of supplementing moringa (*Moringa oleifera*) leaf meal and pomegranate (*Punica granatum)* peel meal on performance, carcass attributes, immune and antioxidant responses in broiler chickens. Animal Production Science, 59, 288-294. doi: 10.1071/AN17390
53) Safrida, S., Nonong N. and Khairil K. 2020. Effects of *Moringa oleifera* leaves powder in fish feed toward growth rate and health of Colossoma macropomum. Biosaintifika, 12 (2), 186-191.
54) Sanchez, N.R., Sporndly, E. and 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, 24-31. doi: 10.1016/j.livprodsci.2005.09.010
55) Shankhpal, S.S., Waghela, C.R., Sherasia, P.L., Sridhar ,V., Srivastava, A.K. et al. 2019. Effect of feeding Moringa (*Moringa oleifera*) as green fodder on feed intake, milk yield, microbial protein synthesis and blood profile in crossbred cows. Indian Journal of Animal Nutrition, 36(3), 228-234. doi: 10.5958/2231-6744.2019.00038.0

56) Sharma, H., Makwana, M.C., Kalamkar, S.S. 2021. Constraints faced by the members of organised and unorganized sector of milk producers in Gujarat. Journal of Livestock Science 12: 23-30. doi. 10.33259/JLivestSci.2021.23-30
57) Sherrif, A. 2014. Incorporation of *Moringa oleifera* in Nile tilapia (*Oreochromis niloticus*) diet and its effect on growth performance and immune status Journal of veterinary science, 1(1), 806-814.
58) Shi, H.H., Liao, J.M., Li, Y., Guo, L., Wang, C., Peng, Z.T. et al. 2018. Feeding value of woody forage in pig production and treatment technology of anti-nutritional factors. Pratacultural Science, 35, 1556–1567.
59) Shih, M.C., Chang, C.M., Kang, S.M. and Tsai, M.L. 2011. Effect of different parts (leaf, stem and stalk) and seasons (summer and winter) on the chemical compositions and antioxidant activity of *Moringa oleifera*. International Journal of Molecular Sciences, 12(9), 6077-6088. doi: 10.3390/ijms12096077
60) Soliva, C.R., Kreuzer, M., Foid, N., Foid, G., Machmüller, 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. doi: 10.1016/j.anifeedsci.2004.10.005
61) Stevens, C.G., Ugese, F.D., Otitoju, G.T. and Baiyeri, K.P. 2015. Proximate and anti-nutritional composition of leaves and seeds of *Moringa oleifera* in Nigeria: a comparative study. Agro-Science, 14(2), 9-17. doi: 10.4314/as.v14i2.2
62) Su B, and Chen X, 2020. Current status and potential of *Moringa oleifera* leaf as an alternative protein source for animal feeds. Frontiers in Veterinary Science, 7, 1-13. doi: 10.3389/fvets.2020.00053
63) Sultana, N., Alimon, A.R., Haque, K.S., Sazili, A.Q., Yaakub, H. et al. 2014. The effect of cutting interval on yield and nutrient composition of different plant fractions of *Moringa oleifera* tree. Journal of Food, Agriculture and Environment, 12(2), 599-604.
64) Thierry, N.N., Léopold, T.N., Didier, M., Moses, F.M.C. 2013. Effect of pure culture fermentation on biochemical composition of *Moringa oleifera* lam leaves powders. Food and Nutrition Sciences, 4, 851–859. doi: 10.4236/fns.2013.48111
65) Valdivie-Navarro, M., Martinez-Aguilar, Y., Mesa-Fleitas, O., Botello-Leon, A., Hurtado, C.B. et al. 2020. Review of *Moringa oleifera* as forage meal (leaves plus stems) intended for the feeding of non-ruminant animals. Animal Feed Science and Technology, 260, 114338. doi: 10.1016/j.anifeedsci.2019.114338
66) Vitti, D.M., Nozella, E.F., Abdalla, A.L., Bueno, I.C., Silva Filho, J.C., Costa, C. et al. 2005. The effect of drying and urea treatment on nutritional and anti-nutritional components of browses collected during wet and dry seasons. Animal Feed Science and Technology, 122, 123–133. doi: 10.1016/j.anifeedsci.2005.04.007
67) Wang, J.H., Cao, F.L., Zhu, Z.L., Zhang, X.H., Sheng, Q.Q., Qin, W.S. 2018. Improvement of quality and digestibility of *Moringa oleifera* leaves feed via solid-state fermentation by *Aspergillus Niger*. International Journal of Chemical Reactor Engineering, 6, 1–14. doi: 10.1515/ijcre-2018-0094
68) Zeng, B., Sun, J.J., Chen, T., Sun, B.L., He, Q. et al. 2018. Effects of *Moringa oleifera* silage on milk yield, nutrient digestibility and serum biochemical indexes of lactating dairy cows. Journal of Animal Physiology and Animal Nutrition, 102(1), 75-81. doi: 10.1111/jpn.12660