



Moringa oleifera: The Miracle Tree and its Potential as Non-conventional Animal Feed: A Review

Nazish Rizwan¹, Danish Rizwan², M.T. Banday¹

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ABSTRACT

Moringa oleifera, a member of the plant family *Moringaceae*, has been recognized to have an abundance of nutrients and bioactive substances with the potential to positively affect health. Moringa has proven to be a versatile plant, with every part of it being used as either a food or a therapeutic agent. The favorable results of different scientific investigations on the use of Moringa in human nutrition have prompted a quest to investigate its potential application in the livestock sector as an alternative to traditional animal feed. Moringa, being an excellent source of nutrients, particularly proteins, can be used as a source of protein in animal diets or as an alternative to conventional livestock feed and fodder. Many research articles have recently been published suggesting that Moringa can be utilized as an unconventional feed or as a fortification agent in animal feeds at inclusion levels that have no negative impact on health, survival, mortality, growth rate, or reproduction. Furthermore, *Moringa oleifera* has been discovered to have an important role in the management of some animal illnesses, particularly avian coccidiosis, by exhibiting anti-coccidial properties.

Key words: Feed, Moringa, Livestock, Poultry, Ruminants.

Moringa oleifera (MO) is native to northern India and northern Europe, but it is also grown in the Red Sea region and other parts of Asia and Africa, including the United States (Singh *et al.* 2019). *Moringa oleifera* is the most promising tree, with nutritional and therapeutic characteristics as well as environmental benefits. *Moringa oleifera* has a diverse range of applications. Water purification, human consumption, medicine, fuel wood, dye, conservation, cattle fodder and green manure are just a few of them (Koul and Chase 2015). Natural resources, economic activities, food security, health, society and physical infrastructure, as well as society in general, are all affected by climate change. As per a report of FAO, 2009 livestock sector accounts for 18% of worldwide GHG emissions (7.1 billion tonnes CO₂ equivalent). Although it produces just 9% of global CO₂, it produces 65% of human-related N₂O and 35% of CH₄, which have 310 times and 23 times the global warming potential (GWP) of CO₂, respectively. Considering these facts it is quite clear that the conventional feeding system is unsustainable and poses serious environmental challenges. Moreover due to high cost associated with conventional feed production, particularly due to fortification of feed with vitamins, minerals and proteins to safeguard animals from various dietary deficiencies, livestock industry faces a great challenge to survive especially in under-developed and developing countries. Being the most expensive and prime limiting factor in feed formulations, conventional protein diets are costlier and hence pave way for searching alternative, non-conventional, relatively cheaper sources for formulation of livestock feed. In order to form an economically viable and ecofriendly livestock feed production system, the research has been focus towards exploring numerous plants and agricultural by products for their potential to serve as animal feed or as a part of feed formulation, supplying essential nutrients (Su and Chen 2020). In this context many plants have been analyzed for their nutrient content and they have shown promising results. *Moringa oleifera*, the

¹Division of Livestock Production and Management, Faculty of Veterinary Sciences and Animal Husbandry, Shuhama-191 202, Srinagar, Jammu and Kashmir, India.

²Department of Food Science and Technology, School of Applied Sciences, University of Kashmir, Hazratbal-190 006, Jammu and Kashmir, India.

Corresponding Author: Nazish Rizwan, Division of Livestock Production and Management, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar-190 025, Jammu and Kashmir, India. Email: nazishkirmani@gmail.com

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Miracle tree, native to sub Himalayan region, is known to possess an excellent nutritional profile which has been studied extensively for many years for exploring its potential to be used in formulation of livestock feed. Being rich in nutrients, Moringa leaves, fresh pods, seeds and roots are widely used as human food and animal feed with various research investigations associating Moringa leaf meal with fast growth, better utilization by animals including cattle, goats, chicken and fish along with high nutritional value. A good amount of literature is available to support the fact that *M. oleifera* especially its leaf can be used as an alternative protein source in animal husbandry as it has an excellent nutritional profile (Nouman *et al.* 2013).

Moringa oleifera

Origin, botanical and pedo-climatic description

Moringaceae, monogeneric plant family includes genus *Moringa*, encompassing 13 plant species. These species

include *Moringa arborea*, *Moringa rivae*, *Moringa borziana*, *Moringa pygmaea*, *Moringa longituba*, *Moringa stenopetala*, *Moringa ruspoliana*, *Moringa ovalifolia*, *Moringa drouhardii*, *Moringa hildebrandi*, *Moringa peregrine*, *Moringa concanensis* and *Moringa oleifera* (Leone *et al.* 2015). However *Moringa oleifera*, native to South Asia, particularly in India, Srilanka, Pakistan, Afghanistan, Bangladesh and some parts of Africa and Saudi Arabia, is the best known among *Moringaceae* family. It is commonly known as Drumstick tree, Miracle tree, benoil tree, ben oil tree and horseradish tree (Trigo *et al.* 2020). There are several vernacular names of *Moringa* plant in India such as Shigru, Shobhanjana, Teekshnagandha, Aksheeva, Mochaka, Munaga, Sajana, Saragavo, Shegata, Sahajano, Sitachini, Daintha, Kelor, Marum, Dandalonbin and Dandalun (Debajyoti *et al.* 2017). Table 1 represents the scientific classification of *Moringa oleifera*.

Moringa oleifera is a fast growing, deciduous, soft wood tree, capable of reaching a height of about 12 m. The tree grows well in tropical and subtropical regions with an average rainfall of about 2000 mm and good sunlight. A temperature of 19-35°C favors optimal growth of this plant. Owing to its good drainage, it is capable of growing in wide range of soil types, but grow best in slightly acidic to alkaline sandy loam soil. It is also capable of withstanding extreme temperatures, from over temperatures of up to 48°C to slight frost (Saini *et al.* 2016). The tripinnate, compound, feathery leaves grow mostly at the tips of the branches. *Moringa* flowers have yellow-white colored petals with slight pleasant fragrance. The fruit of this tree is a trilobe capsule with a slender pod with 15-20 seeds, which changes color from green to brown upon maturity. The seeds are round or triangular in shape, each covered by a woody shell and three papery wings (Su and Chen 2020).

Nutritional composition of *Moringa oleifera*

The "Miracle tree", *Moringa oleifera* is known for its nutritional and nutraceutical potential. All parts of this plant including leaves, pods, seeds, flowers, fruits and roots are edible and form a part of traditional diet of people living in tropical and sub-tropical countries (Islam *et al.* 2021). The different parts of *Moringa* act as the storehouse of various essential nutrients (Table 2). The leaves of *Moringa* contain approximately 20-35% protein on dry weight basis with majority of essential amino acids. They also contain high content of minerals such as calcium, potassium, zinc, iron, copper and magnesium (Mohanty *et al.* 2021). The leaves of *Moringa* plant are known for their omega 3 and omega 6 polyunsaturated fatty acid content especially that of α linolenic acid and linolenic acid. Palmitic acid has been noted to be the main saturated fatty acid present in these leaves, accounting for about 16-30% of the total fatty acid content. The leaves, flowers and pods of *Moringa* plant are also rich in vitamins like vitamin A, vitamin C, vitamin D, vitamin E, riboflavin, folic acid, pyridoxine and nicotinic acid (Gopalakrishnan *et al.* 2016). As compared to leaves, stem

and immature pods of *Moringa oleifera* have slightly lower nutritive content. The pods contain low amount of lipids and proteins, have abundance of dietary fiber and have a significant amount of unsaturated essential amino acids (Granella *et al.* 2021). The seed of *Moringa* plant are having a good oil content ranging between 30-40% (Leone *et al.* 2015), rich in saturated and unsaturated fatty acids including oleic acid, palmitic acid, stearic acid and arachidic acid (Saini *et al.* 2016). The seeds also contain a substantial amount of macronutrients and micronutrients such as sodium, potassium, calcium, magnesium, phosphorus, zinc, copper; and essential and hydrophobic amino acids (Liang *et al.* 2019). *Moringa* flowers are also rich in many nutrients, including proteins, dietary fiber, lipids, carbohydrates, potassium, calcium, polyunsaturated fatty acids and antioxidants (tocopherols) (Sánchez-Machado *et al.* 2010).

Phytochemical composition of *Moringa oleifera*

The human population around the globe is known to use medicinal plants for treatment of various pathological conditions since time immemorial. These plants form an important tool in comprehensive health care. The numerous therapeutic effects of *Moringa* have been discerned in both Ayurvedic and Unani medicine. All parts of this plant exhibit pharmacological effect and have been used as a traditional medicine in tropics and sub tropics since ages (Islam *et al.* 2021; Mughal *et al.* 1999). *Moringa oleifera* is a reservoir of phytochemicals such as phenolic acids, flavonoids, flavonols, steroids, polyphenols, isothiocyanates, glucosinolates, sterols, sitosterols, phytosterols, terpenoids, catechins, caffeic acid, ferulic acid, procyanidins, chlorogenic acid and alkaloids, distributed among different parts of the plant (Brilhante *et al.* 2017). The various functional and therapeutic properties of *Moringa oleifera* are accredited to this broad range bioactive compounds identified in different parts of this plant using various identification techniques such as GC-MS and HS-SPME (Falowo *et al.* 2018). The presence of these phytochemicals constitutes a basis for extensive research and currently, the scientific community on an international level is exploring the potential of this tree in the field of food, feed, medicine and cosmetics. Extracts of *M. oleifera* plant parts have been recognized to possess anti-inflammatory, hypoglycemic, hypolipidemic, antipyretic, analgesic, neuroprotective,

Table 1: Taxonomical classification of *Moringa oleifera*.

Kingdom	<i>Plantae</i>
Sub-kingdom	<i>Tracheobionta</i>
Super division	<i>Spermatophyta</i>
Division	<i>Magnoliophyta</i>
Class	<i>Magnoliopsida</i>
Sub- class	<i>Dilleniidae</i>
Order	<i>Brassicale</i>
Family	<i>Moringaceae</i>
Genus	<i>Moringa</i>
Species	<i>oleifera</i>

Table 2: Nutritional composition of leaves, seeds and pods of *Moringa oleifera* per 100 g.

Nutrient	Dry leaves	Fresh leaves	Pods	Seeds
Protein (g)	29.4	6.7	2.5	35.97
Calories	205	92	26	-
Fat (g)	5.2	1.7	0.1	38.67
Carbohydrates (g)	41.2	12.5	3.7	8.67
Moisture%	7.5	75	86.9	-
Fibre (g)	12.5	0.9	4.8	2.87
Potassium (mg)	1236	259	259	235.7
Phosphorus (mg)	252	70.8	110	75
Calcium (mg)	2185	440	30	45
Sulphur (mg)	870	137	137	0.05
Iron (mg)	25.6	0.85	5.3	-
Magnesium (mg)	448	24	24	635
Copper (mg)	0.6	0.07	3.1	5.20
Vitamin B1 (mg)	2.02	0.06	0.05	0.05
Vitamin B2 (mg)	21.3	0.05	0.07	0.06
Vitamin B3 (mg)	7.6	0.8	0.2	0.2
Vitamin C (mg)	17.3	220	120	4.5
Arginine (mg)	1325	406.6	360	540
Histidine (mg)	613	149.8	27.5	98
Lysine (mg)	1325	288	37.5	73
Tryptophan (mg)	425	107	80	-
Methionine (mg)	350	117.7	140	65
Valine (mg)	1063	476	135	125
Phenylalanine (mg)	1388	310.3	40	165
Threonine (mg)	1188	117.7	98	95
Leucine (mg)	1950	492.2	650	214

Source: (Dhakar *et al.* 2011; Gopalakrishnan *et al.* 2016; Liang *et al.* 2019; Price 1985).

anticancer, cytotoxic, anti-proliferative, anti-leukemia, anti-hepato-carcinoma and chemo-protective properties (Bhattacharya *et al.* 2018; Mahfuz and Piao 2019; Ravani *et al.* 2017). Table 3 summarizes the phytochemical compounds present in different parts of *Moringa oleifera*.

Various studies have suggested that Moringa is rich in anti-microbial compound, Pterygospermin, which is mainly concentrated in flowers and roots of the plant. This compound has been found to be effective as a powerful antibiotic and fungicide, showing a good response against microbial species like *Fusarium solani*, *B. subtilis*, *S. aureus*, *S. areogunosa* (Abdulkadir *et al.* 2015; Pandey 2012). Antibiotic activity has also been associated with presence of lipophilic components and various metabolites namely carboxylic acid, 2, 4-diacetylphloroglucinol and Chitinases. A significant percentage of antioxidants like Superoxide dismutase (SOD), catalase (CAT), glutathione S-transferases (GST) have been found to be present in the leaf extract of Moringa plant (Moyo *et al.* 2013).

Anti-nutritional factors in *Moringa oleifera*

The undesirable chemical compounds present in both cultivated and wild plant species are termed as anti-nutritional compounds or anti-nutritional factors or anti nutrients or allelochemicals. These compounds are

synthesized as secondary metabolites via normal metabolic pathways in plants, intended for own defense. However they have an impact on digestibility, bioavailability and utilization of nutrients especially proteins, minerals and vitamins in food derived from plants and also determine the use of a particular plant as food and fodder (James and Zikankuba 2017). These anti nutritional factors include nitrates, oxalates, tannins, phytates, trypsin inhibitors, saponins, protease inhibitors, gossypol and cyanogenic glycosides (Su *et al.* 2020). It has been seen that *Moringa oleifera* leaves has presence of anti- nutritional compounds such as tannins, saponins and lignin but in negligible amounts. There exists a variation in amount of these anti-nutritional components owing to diverse growth conditions and cultivars (Shih *et al.* 2011). The leaves of Moringa contain 21 g/kg and 10.5 g/kg phytates and oxalates respectively. Moreover negligible amount of tannins, saponins, trypsin inhibitors and amylase inhibitors and no traces of cyanogenic compounds has been noted (Makkar and Becker 1997; Teixeira *et al.* 2014). The saponins are present in Moringa leaves but they amount for about 4.7-5 g/kg dry weight only (Moyo *et al.* 2013). Another study reported 10.58 mg phytates, 334.33 mg oxalates, 8.19 mg tannins and 3998.30 mg hydrogen cyanide per 100 g of Moringa leaves (Auwal *et al.* 2020). The level of oxalates

Table 3: Phytochemical composition of *Moringa oleifera*.

Plant part	Compounds
Leaves	Niazirin and Niazirin-nitrile glycosides, benzyl isothiocyanate, Niaziminin A, Niaziminin B, Niazimicin, pyrrolemarumine 400-O-a-L-rhamnopyranoside, hydroxyphenylethanamide, alpha and gamma-tocopherol, 2, 3-Butanedione.
Seeds	Methionine, cysteine, 4-(alpha-L- rhamnopyranosyloxy) benzylglucosinolate, Moringine, benzylglucosinolate, niazimicin, niazirin.
Pod	Isothiocyanate, nitrites, thiocarbamates, O-(1heptenyloxy) propyl undecanoate, O-ethyl-4-(alpha-L-rhamnosyloxy) benzyl carbamate, methyl-p-hydroxybenzoate, beta-sitosterol.
Bark	4-(alpha-L-rhamnopyranosyloxy) benzylgiucosinolate.
Flowers	D-glucose, quercetin, isoquercetin, kaempferol, kaempferitrin and ascorbic acid, protein, D-mannose.
Root	Moringine, moringinine, spirachin, 1,3-dibenzyl urea, alpha- phellandrene, p-cymene, Deoxy-niazimicine, 4-(alpha-L-rhamnopyranosyloxy)benzylglucosinolate.
Stem	4-hydroxyl mullein, vanillin, octacosonoic acid, beta- sitosterone and beta- sitosterol.

Source: (Paikra *et al.* 2017).

has been estimated in *Moringa* leaves and it is present in low concentrations (25.7 mg g^{-1}), which is much lower than spinach which has an oxalate concentration of 125.7 mg g^{-1} (Radek and Savage 2008). Trypsin inhibitors have not been detected in *Moringa* leaves (Gidamis *et al.* 2003). The anti-nutritional compounds in *Moringa* seeds have been noted to be lower than leaves. The seeds of *Moringa* contain 252.08 mg/100 g saponins and 47.93 mg/100 g tannins (Muhammed Fayis 2017). Phytates have been found to be the most abundant anti nutritional compound in *Moringa* seeds. The phytate content in *Moringa* seeds was found to be $1380.6 \text{ mg PAE/100 g}$. Moreover saponins and tannin content in *Moringa* seeds was found to be $154.95 \text{ mg DE/100g}$ and 62.2 mg CE/100 g respectively (León-López *et al.* 2020). Igwilo *et al.* (2013) reported presence of tannins, oxalates, phytates, saponins and cyanogenic glycosides in *Moringa* roots. The tannins and oxalates were present in high content (45 mg/100 and 17.08 mg/100 g respectively). The content of saponins, phytates and cyanogenic glycosides showed presence in lower concentrations (4.20 mg/100g , 0.07 mg/100 g and 2.72 mf/100 g respectively) (Igwilo *et al.* 2013). Although these factors are present in negligible amounts, their effects can further be minimized by using various processes like chopping, soaking, drying, fermentation and steaming (Moyo *et al.* 2013; Radek and Savage 2008; Teixeira *et al.* 2014).

Application of *Moringa oleifera* in livestock feeding

The leaves of woody plants are known for their high nutritional composition. However their use as animal feed is restricted due to presence of excessive fiber content and anti-nutritional compounds that have an adverse impact on the palatability, digestibility and nutrient utilization. This forms the basis for determining the suitability of a tree or plant to be used as an animal feed (Su and Chen 2020). The remarkable nutritional and phytochemical composition of *Moringa oleifera* along with low amount of anti-nutritional factors, makes it suitable for animal feed. The use of *Moringa* as a feed or a feed supplement dates back to 1962 (Ramachandran *et al.* 1980). The young branches, leaves and seed residues left after oil extraction have been fed to farm animals. In the recent past, *Moringa* is being considered

to be used as an effective alternative to conventional diets for livestock. However the inclusion levels are significantly lower as the mode of action of improvement of production performance and health status is still being explored and understood (Mahfuz *et al.* 2019).

Poultry

Moringa oleifera can be used in poultry as a dietary supplement due to its nutritional and therapeutic value (Abdel-Wareth and Lohakare 2021). Various researchers have used leaf meal or leaf extract of this plant in poultry and it has been able to produce positive results. Improvement in bowel health, increased weight gain, decrease feed intake, improved feed conversion ratio, increased immune response and good anti-oxidant responses in broilers has been attributed to the use of *Moringa* leaf meal as feed. It has been seen that broilers supplemented with *Moringa oleifera* have considerable increase in the level of high density lipoproteins in serum along with a significant decrease in Low density lipoproteins. This effect has been associated with higher fiber content in *Moringa* which results in lowering of cholesterol levels in the body. Hypocholesterolemic effect has been observed in egg cholesterol content which is much lower when poultry feed is supplemented with *Moringa* leaves (Olugbemi *et al.* 2010). Broilers fed with diets containing 5% *Moringa* leaf meal for 7 weeks have shown increased body weight and higher total feed intake and improved feed conversion ratio compared to a control group (Tazi 2014). It has also been reported that Broilers fed with 0.05% of moringa fruit meal and 0.1% of moringa leaf meal for 42 days resulted in improved growth performance and carcass yield (David *et al.* 2015). As reported by Alabi *et al.* 2017, inclusion of aqueous extracts of *Moringa oleifera* leaves at a concentration of 90 ml/liter of drinking water of broiler chicken can result in reduction of feed intake by about 12.83% and an overall improvement in the feed conversion efficiency, suggesting the possible use of this extract as a replacement for synthetic growth promoters (Alabi *et al.* 2017). A research study conducted by Rehman *et al.* (2018) studied the impact on *Moringa* leaf powder supplementation on the quality of meat and bone morphometry in broilers and it was observed that

diameter of breast muscle fibers, weight and weight length index of the tibia bone increased significantly with administration of 12-15 g/kg of Moringa leaf powder. Improvement of total hemoglobin percentage, total red blood cell count and packed cell volume was recorded in broilers upon inclusion of up to 20% of Moringa in feed. In case of layers it has been reported that addition of 5-10% Moringa in diets led to improved yolk color and albumin height, while as addition of about 10-20% Moringa leaf meal in place of sunflower seed meal improved laying performance, egg weight, increases feed intake and increased feed conversion ratio by 20% (Rehman *et al.* 2018). Abou-Elezz Fouad Mohammed *et al.* 2012 reported that supplementation of feed with fresh leaves of *Moringa oleifera* could improve egg production, egg yolk color and egg mass (Abou-Elezz Fouad Mohammed *et al.* 2012). Supplementation of feed of 27 week old hy-line grey commercial layers with Moringa leaf at 5% resulted in higher feed conversion ratio, improved protein absorption without any notable effect on laying performance and egg quality (Lu *et al.* 2016). Similar effect of Moringa leaf supplementation in layer diet on production performance and egg quality has been observed by (Briones *et al.* 2017). A research study on 64 week old hy-line brown hens suggested that dietary supplementation with Moringa leaves improved egg production, weight and mass significantly. Haugh unit and shell thickness also showed significant improvement as a response to Moringa leaf supplementation at a rate of 3, 6 and g/kg (Abdel-Wareth and Lohakare 2021). The administration of 2-6% of Moringa leaf powder with diet to laying hens significantly decreases the cholesterol content in egg yolk. Moreover improvement in egg production, egg mass, shell thickness, yolk color, beta carotene, magnesium and calcium content in yolk has been noted by inclusion of 4-6% Moringa leaf powder (Bidura *et al.* 2020). These research findings clearly suggest that feeding Moringa leaf meal to chicken has no adverse effect on the normal physiology and growth with use within 1-10% considered to be the safe level (Mahfuz and Piao 2019). Apart from inclusion of leaves, Moringa seeds and pods have also been used to supplement poultry feed. Improved yolk color and higher percentage of linoleic acid content in yolk was observed when layers were fed with Moringa seed meal (Mabusela *et al.* 2018). The effect of Moringa seed meal on nutrient digestibility in finisher broiler chicken has been evaluated. It has been observed that inclusion of 0.02% seed meal in finisher broiler chicken enhances the nutrient digestibility (Abdulkarim *et al.* 2018). A significantly lower cholesterol level in egg yolk has been reported in hy-line layers fed with Moringa pod meal (Ahmad *et al.* 2017). Moringa stem meal as a supplement was fed to laying ducks along with basal diet at varying concentrations (0-4%). The ducks fed with 2% Moringa stem meal showed an increase in average daily feed intake and average daily gain. An improvement in feed conversion rate was observed in ducks fed with 4% Moringa stem meal. Supplementation also had a positive effect on egg quality and the antioxidant activity

of meal improved the immunological index as well (Yang *et al.* 2020). Moringa stem meal, rich in crude fiber, fed to geese at varying levels ranging between 0-100 g/kg resulted in increase in feed/gain ratio in a linear manner with the increase in Moringa stem meal inclusion. The inclusion of 100g/kg of Moringa stem meal resulted in significant decrease in blood glucose level and an increase in alanine transaminase enzyme activity (Zhai *et al.* 2020).

Ruminants

The potential of *Moringa oleifera* to be used as ruminant feed has been investigated as it is rich in nutrients but most distinct feature which has played a key role for its consideration as ruminant feed is its methanogenic inhibitor content which has the capability to decrease methane emission in ruminants. Methanogenic inhibitors of Moringa plant pose a great potential to be utilized on a large scale for livestock feeding programs which aim at minimizing the methane emission. Around 17% decrease in daily methane emission was observed in animals fed with *Moringa oleifera* and a total of 50% decrease in emission was recorded when it replaced soybean meal as feed (Elghandour *et al.* 2017; Soliva *et al.* 2005).

Cattle

Conventional low quality diet supplemented with Moringa leaves as protein additive has been noted to increase the dry matter intake, digestibility of diet and milk production cows of Creole Reyna breed (Reyes Sánchez *et al.* 2006). Total mixed ration at level of 180 g/kg supplemented with Moringa silage fed to lactating Holstein cows resulted in higher milk yield as compared to control cows. The milk was also characterized by better anti-oxidative potential (Cohen-Zinder *et al.* 2016). Cows fed with formulated ration along with 20% inclusion of *Moringa oleifera* leaf had higher mean value of milk fat, total solids, crude protein and casein when compared to those fed with formulated ration containing 20% soybean meal (Mendieta-Araica *et al.* 2011). Dietary supplementation of Moringa at the rate 6% in dairy cows resulted in milk with improved fat content (Dong *et al.* 2019). Partial substitution of alfalfa hay and maize silage with *Moringa oleifera* silage showed no negative effect on milk yield, nutrient digestibility and biochemical indexes of lactating Holstein cows (Zeng *et al.* 2018). Lactating cross bred cows were fed 15.0 kg of Moringa as green fodder for 90 days to evaluate its effect on milk yield, microbial protein synthesis and blood profile. Shankhpal *et al.* 2019 reported that feeding cows with Moringa resulted in improved α carotene content in milk and intestinal flow of microbial nitrogen. Furthermore the cholesterol content of milk decreased by 17.60% (Shankhpal *et al.* 2019). Moringa leaf meal fed to pregnant Holstein cows at the rate of 16.66 g/100 kg body weight, resulted in improved blood profile, antioxidant status and udder health in these cows (Kekana *et al.* 2020). Micro supplementation of diet of lactating Jersey cows with Moringa leaf meal showed a significant effect on the blood biochemistry and udder health of cows. A notable

increase in serum protein and immunoglobulin G was observed. Micro supplementation with Moringa leaf meal at 60 g/day/cow remarkably reduced oxidative stress, which in turn resulted in improvement of milk quality in terms of milk fat content and immunity in lactating cows (Kekana *et al.* 2019).

Buffalo

Effect of substitution of soya bean meal by Moringa leaf meal on rumen fermentation, nutrient digestibility and growth performance of 8-9 months old buffalo calves has been investigated. It was noted that Moringa leaf inclusion at the rate of 15% and 20% in concentrate mixture resulted in increase in digestibility of dry matter, crude fiber and organic matter, while the digestibility of crude protein showed a decline. Inclusion of Moringa leaf meal at 15% inclusion rate resulted in improved final body weight, daily weight gain, feed conversion efficiency and plasma insulin growth factor I without any noticeable adverse effect on the growth of buffalo calves. (Abdel-Raheem and Hassan 2021). The replacement of concentrate mixture and calf starter up to 10% by Moringa leaf meal resulted in better body weight gain in Murrah calves (Roy *et al.* 2018).

Sheep

Defatted Moringa seed meal at a level of 2-6 g/day when used as an additive in Barbarine lamb hay-soybean meal exhibited no effect on diet digestibility. The inclusion of intermediate level *i.e.* 4 g/day Moringa seed meal in diet resulted in improved rumen fermentation (Ben Salem and Makkar 2009). Replacement of conventional concentrate mixture by Moringa foliage as protein supplement at a level of 75% and 100% in rice straw diet resulted in favorable growth performance, leaner carcass and higher meat proportion in lambs (Sultana *et al.*, 2017). The *Moringa oleifera* leaf meal inclusion at level of 25% in concentrate mixture resulted in the improvement of body condition score in Deccani lambs being reared under intensive farming system (Bala and Ramana 2020).

Goat

Goats fed with Moringa leaves at 20 and 50% inclusion levels have shown increased live weight gain, digestibility of dry matter, crude protein and organic matter (Aregheore 2002). Babiker *et al.* 2017 reported that there was increase in oxidative stability and vitamin C content of milk in ewes and goats supplemented with *Moringa oleifera* leaf at 25% inclusion level when compared to those with Alfalfa hay. This may be attributed to presence of various nutrients along with essential elements such as calcium, potassium and magnesium (Babiker *et al.* 2017). The concentrate diet of black Bengal goats when replaced by Moringa foliage resulted in improved average daily weight gain and better nitrogen retention clearly depicting the potential of Moringa to serve as alternative to conventional concentrate mixture (Sultana 2015). Inclusion of Moringa leaf meal at a level of

15%, replacing 75% sesame meal in diet of lactating Anglo Nubian goats improved milk yield and composition in terms of total solids and lactose content. It also improved the level of unsaturated fatty acids and conjugated linoleic acid. Moreover, Moringa leaf meal also enhanced rumen fermentation, feed intake and nutrient digestibility (Kholif *et al.* 2015). Oral administration of Moringa leaf extract for 88 days to Nubian goats as apart from basal diet resulted in significant increase in milk yield, milk energy, total solids, solid not fat, protein, lactose and ash content with a linear relationship with dose at which extract was administered. In general supplementation with Moringa extracts led to enhancement of milk yield by about 6% and an increase in total conjugated linoleic acid by 17.4-23.2% (Kholif *et al.* 2018). Replacement of conventional concentrate mixture with dried Moringa leaves resulted in improvement of body weight without affecting feed intake and health of Mehsana goat (Pawar and Ankuya 2017).

Non-ruminants

Pigs

The literature related to the use of Moringa as feed for Pigs is limited and greatly restricted to the laboratory scale research. Some researchers have studied the impact of using Moringa foliage as a replacement for conventional pig feed. It has been noted that finisher pig when fed with Moringa leaf at 5% intake level showed no negative impact on feed conversion ratio, cutability, backfat thickness and other carcass traits. Although the pigs fed with more than 5% Moringa leaf meal exhibited better daily feed intake, their feed conversion ratio was lower as compared to those fed at 5% or below intake levels (Mukumbo *et al.* 2014). The research findings of Dany *et al.*, 2016 suggested that inclusion of Moringa leaf at 40% inclusion rate in Mexican hairless pigs had no effect on growth performance (Dany *et al.* 2016). Furthermore it has been noted that increase in consumption of Moringa feed resulted in increased amount of unsaturated fatty acids in fat and meat. However as reported that 10% inclusion level of Moringa leaf in feeds of commercial prestarter and starter pigs had no impact on the average daily weight gains, highlighting the fact that a specific meal needs to be formulated for pigs based on their growth stage (Acda *et al.* 2010). Weaner pigs fed with Moringa leaf meal at varying inclusion levels ranging between 1-5% showed no significant effect on the final body weight and carcass parameters. However the growth rate of weaner pigs fed with 5% Moringa leaf meal was better as compared to those fed with 2.5% meal and control diets (Oduro-Owusu *et al.* 2015). Cross bred finishing pigs fed with Moringa meal at inclusion rates 0, 3, 6 and 9%, resulted in significant increase in the daily weight gain with less impact on pork quality and amino acid profile. The fatty acid profile of finishing pigs underwent modification with an increase in unsaturated fatty acid content upon consumption of Moringa meal at 6% inclusion levels (Dong *et al.* 2019).

Rabbits

Weaner rabbits fed with Moringa leaf meal at an inclusion level of 0-20% resulted in increase in average daily weight gain but no significant difference was observed in blood parameters (Nuhu 2010). The growing rabbits fed with Moringa leaf meal at varying inclusion levels in diets (up to 15%) exhibited no adverse effects on the hematological and serum biochemical response (Ewuola *et al.* 2012). Feeding New Zealand white rabbits with Moringa leaf meal as a substitute for alfalfa meal at level of 0%, 10%, 20% and 30% showed significant impact on growth performance, nutrient digestibility, meat quality, antioxidant capacity and biochemical parameters. The average daily weight gain and feed conversion ratio was much better at 20% inclusion level of Moringa leaf meal. The leaf meal also had a significant impact on serum albumin, low density lipoproteins, cholesterol levels and superoxide dismutase activity (Sun *et al.* 2018). Rabbits fed with 30% Moringa leaf meal had a significant increase in body weight (Safwat *et al.* 2014).

Role of *Moringa oleifera* in disease management

Avian coccidiosis which is regarded as the most frequently encountered disease of importance to poultry, resulting in mortality of broiler globally has been so far tackled by use of anti-coccidial drugs. However plants with medicinal value could serve as an alternative to synthetic drugs. Extracts of Moringa leaves have been found to be effective against various bacterial, viral and parasitic infections. Acetone extracts of Moringa fed at the rate of 1-5 g/kg body weight of broiler chicken infected with *Eimeria* species showed improved gain in body weight and a significantly milder faecal scores. Moreover as compared to infected, untreated group of birds, those fed with moringa extracts had significantly higher hemoglobin and red blood cell count (Ola-Fadunsin and Ademola 2013). Another research study evaluated the protective function of methanolic moringa extracts in chicken infected with Newcastle disease, which has a profound economic impact on poultry farms due to high mortality rates associated with this disease. Chicken fed with methanolic extracts of moringa at the rate of 200mg/kg body weight for 42 days exhibited noteworthy survival rates validating the protective effect of Moringa against Newcastle disease (Eze *et al.* 2012). Oral administration of aqueous extracts of Moringa leaves at a dose of 150mg/kg body weight for 21 days at an interval of 48 hours to sheep coinfectd with *Fasciola gigantica* and *Colostritidium novyi* resulted in reduced fecal egg counts, improved gain in body weight and significant decrease in level of interleukin 2, interleukin 17 and immunoglobulin G (El Shanawany *et al.* 2019).

CONCLUSION

M. oleifera could be a viable option in areas where traditional crops are being hampered by climate change. Furthermore, because all parts of *M. oleifera* are edible (leaves, roots,

flowers, pods and seeds), they can be included into a variety of food matrices, enriching their nutritional profile with high quantities of proteins, fibre, vitamins and antioxidants. It also contains anti-inflammatory, anti-asthmatic, cholesterol-lowering, antimicrobial and analgesic properties, among others. *Moringa oleifera* has been used as a feed for different animals by various researchers either individually or in combination with conventional feeds at different inclusion levels, highlighting its potential to be used as an alternative to conventional feeds especially due to its rich protein content. Although Moringa is gaining popularity as a supplement in animal feeding system, but complete replacement of conventional feed by Moringa is still under question. The scare information is available pertaining to economics of Moringa if it's used in place of traditional feed. Anti-nutritional factors, however present in substantially lower concentrations, can act as a limiting factor. Therefore it is quite necessary to pretreat the moringa feed in order to inactive the anti-nutritional factors and also properly investigate optimum dose or inclusion levels to be used in order to avoid any negative influence on the growth and reproductive performance of animal.

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