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POTENTIAL OF MORINGA (*MORINGA OLEIFERA* L.) AS LIVESTOCK FODDER AND MITIGATION OF CLIMATE CHANGE – A REVIEW

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SUMMARY

Livestock production in developing countries faces several difficulties such as a general shortage of feed resources, regional availability, and quality. Climate change further exacerbates these problems, leading to a massive reduction in ruminant productivity. Therefore, there is a need for the use of adaptable and resilient forage plants that can also contribute to reducing greenhouse gases. Over the last few years, underutilized crops and trees have captured the attention of plant scientists, nutritionists, and growers. *Moringa oleifera* (moringa) is one of those plants that has been neglected for several years but now is being investigated for its fast growth, higher nutritional attributes, and utilization as a livestock fodder crop. It can be grown as a crop on marginal lands with high temperatures and low water availability, where it is difficult to cultivate other agricultural crops. Moringa tree is well known as an agroforestry tree and has adapted to growing in harsh conditions. It produces a high amount of biomass in a short period and contains high levels of nutrients and biologically active components. All parts of this versatile tree are valuable and have multiple benefits and applications. Therefore, this tree species has great potential and can be used as a forage crop, storing carbon dioxide (CO_2) and improving livestock performance and the livelihoods of farmers in the tropics. This review article is aimed to highlight the use of moringa in livestock as well as suitable growing conditions, cultural practices and its contribution to climate change mitigation.

Keywords: Moringa, livestock, fodder, methane, climate change and mitigation

Livestock sector is a vital subsector of agriculture and plays a prominent role in the socio-economic development of the country. The sector plays a significant role to empower rural women and youth, improve natural resource-use efficiency, and increase the resilience of households to cope with climate shocks (Kumar, 2022). In several countries across the world, the surging demand for livestock products is largely met by large-scale livestock production and associated food chains. Livestock sector contributes to nearly 40 per cent of total agricultural output in developed countries and 20 per cent in developing countries, supporting the livelihoods of at least 1.3 billion people worldwide (FAO, 2022). Thirty-four per cent of global food protein supply comes from livestock. International trade acts as an engine of economic growth. It promotes competition, flow of knowledge, capital and technologies and hence the efficient allocation of scarce resources. With expanding markets, the trade specialization on a large scale and enhance availability of goods at competitive prices leading to increase real income and consumption.

In India, almost entire feed requirement for livestock production is met extensively from crop residues/by-products, grasses, herbages, weeds and tree browses collected from cultivated/uncultivated fields and grazing on common property resources like forests, pastures, village commons and fallow lands (Rawat and Vishvakarma, 2011). The limited land allocation to fodder crops cultivation having only 4% of gross cropped area has resulted in severe deficit of feed supply, restricting efficient livestock production (Islam *et al.,* 2021). As per estimate on demand-supply gap in fodder availability shows a net deficiency of 35.6% green fodder, 10.95% dry fodder and 44% concentrate feed materials in the country (IGFRI Vision, 2050). By 2050, the demand for green and dry feed will be 1012 and 631 million tones, respectively. In the year 2050, with the current rate of expansion in forage supplies, there will be an 18.4% deficit in green fodder and a 13.2% shortfall in dry fodder (IGFRI Vision, 2050). Green forage supply must rise at a rate of 1.69% per annum to satisfy the deficit; however, the area under cultivated fodder accounts for only

4% of the total cultivated land (8.4 million ha) in the country, and has remained unchanged over last few decades. (Dagar, 2017; Halli *et al.,* 2018), which is not adequate to meet the fodder demand. Besides, more emphasis on food grains further add to the fury by limiting area under fodder crops and resultant shortage of fodder production as well as supply of feed (Kumar *et al.,* 2019). This fodder shortage gets increased in dry months (May and October) when the unavailability of fodders increase (Dhillon *et al.,* 2023). In the current scenario, where the probability of increasing area under fodder crops is nearly impossible, it is imminent to adopt a multi-pronged strategy for adequate fodder production to keep pace with the current demand and future challenges (Singh *et al.,* 2022). With the existing genetic pool of livestock, fodders, and forages, the livestock production can be improved by 50% by increasing the quality and quantity of available forages or introducing new highly nutritious plant species as livestock fodder. Trees and browse species have been used as livestock fodder for centuries. Research results from several parts of the world including African countries and India reveals that fodder trees and shrubs are valuable animal feed and play an important role in farming system due to their better adaptation to local environment (Jamala *et al.,* 2013) and drought situation. *Leucaena leucocephala*, *Sesbania sesban*, *Sesbania grandiflora*, *Prosopis cineraria*, *Ailanthus excelsa*, *Morus alba*, *Gliricidia maculata* and *Moringa oleifera* can be cultivated on isolated denuded patches of land for supply of nutritious fodder to graze animals (Kumar *et al.,* 2019). Research scientists are focusing their work on tree species that can provide good quality fodder especially in dry periods when no other fodder is available. *M. oleifera* (moringa) is a remarkable species with its high nutritional value and good biomass production, which can be used as a nutritional supplement (Atreya *et al.,* 2023). In addition, moringa holds great promise for improving livelihoods, improving food security, and improving climate resilience. The present review article covers the potential of *M. oleifera* as a possible valuable resource for livestock fodder.

Significance of moringa

Moringa has been known for centuries as a plant with various benefits, nicknamed 'The Miracle Tree or 'The Magic Tree' (Falowo *et al.,* 2018). Because it is naturally proven to have nutritional content that is considered complete compared to other food-source plants (Jattan *et al.,* 2021). Almost all parts of the versatile plant have various properties; every parts of this plant that have been extensively studied for its nutritional content. And usefulness for the health sector, human food and animal feed, and animal health is the leaf part (Sultana, 2020). Nonetheless, studies have shown that roots, stems, bark, fruits, flowers, and seeds also have various therapeutic properties and high nutritional value (Agoyi *et al.*, 2014; Khattak *et al.,* 2020). According to Leone *et al.* (2016), humans and animals can consume all parts of the moringa tree through leaves, seeds, roots, and flowers. Various studies have shown that this plant has various properties and can be used as a food or feed ingredient because it has a relatively complete nutritional content. The species is mostly used as a traditional medicine and food (Popoola and Obembe, 2013; Jattan *et al.,* 2021). Studies on the benefits of moringa as animal feed such as fish (Afuang *et al.,* 2003), poultry (Alabi *et al.,* 2017), goats (Kholif *et al.,* 2015), sheep (Jelali and Ben-Salem, 2014), pigs (Zhang *et al.,* 2019), beef cattle (Roy *et al.,* 2016) and dairy cattle (Mendieta-Araica *et al.,* 2011) had been carried out to increase the production of this livestock.

Taxonomy, origin and distribution

Moringa is a slender softwood tree that belonging to the family *Moringaceae*, order Capparales, class Magnoliopsida and division Magnoliophyta. The genus Moringa, have 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 concanesis* and *Moringa oleifera* (Leone *et al.,* 2015). However, *Moringa oleifera* L., 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. Moringa was utilized by the ancient Romans, Greeks and Egyptians, and is now widely cultivated throughout the tropical and subtropical regions of the world (Fahey, 2005). It is commonly known as Moringa, Drumstick tree, Miracle tree, Benzoil tree, Ben oil tree and Horseradish tree (Trigo *et al.,* 2021). 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).

Moringa oleifera tree bears spreading, open crown of drooping and fragile branches. The compound tripinnate leaves alternately bear leaflets in opposite pairs and leaf length ranges from 45-90 cm. The leaflets are dark green with red tinged mid veins, entire margins and rounded at apex (Ramachandran *et al.,* 1980). The soft stem wood is light weight and bark is whitish grey, thick and corky. The deep tap root system and spreading tuberous lateral roots provide support to the tree. It may flower twice in a year or round the year. The flowers have pleasant smell and these are produced in 10-25 cm long loose axillary panicles. The flowers are white or ceamy-white in colour, zygomorphic and pentamerous (Vlahof *et al.,* 2002). Calyx contains five sepals which are green, lobed and tubular. Corolla comprises five narrowly spathelate, veined and creamy-white petals. Androecium is comprised of five fertile yellow stamens with alternating five smaller sterile stamens (staminodes). Gynoecium is represented by a single, stalked superior ovary with slender style. Ovary is one celled with double rows of ovules (10-25). Moringa fruit is called as pod and looks like drumstick. Pods are large (10-60 cm long) and turn brown at maturity. The seeds are rounded, one cm in diameter, dark brown to black in color with three papery wings.

Habitat, cultivation and management

Moringa 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. Moringa adapts well to hot, semiarid regions with as little as 500 mm annual rainfall (Ebert, 2014). Once it has been established, its strong antioxidant system helps coping with moderate saline conditions, experiencing only a mild reduction in its mineral quality (Nouman *et al.*, 2012). It is also capable of withstanding extreme temperatures, from over temperatures of up to 48^{0}C to slight frost (Saini *et al.,* 2016). In general, moringa grows best in lowland cultivation, but it also adapts to altitudes above 2000 m (Ebert, 2014). Slightly alkaline clay and sandy loam soils are considered the best media for moringa due to their good drainage (Ramchandran *et al.*, 1980). Moringa tolerates a wide range of soil types and pH (4.5-9) but prefers well-drained soils in the neutral pH range (Paliwal and Sharma, 2011).

Moringa oleifera is propagated in two main ways; by sowing and by cutting. The preference for a propagation mode varies among countries. Traditionally, in Sudan seeds are preferred; while vegetative propagation is common in India, Indonesia and in some areas of West Africa (Leone *et al.,* 2015). As an important economic crop, *M. oleifera* is now cultivated broadly in India, South China, and African countries (Oduro *et al.,* 2008). Moringa yields a high amount of biomass ranging from 43 to 115 t/ha annually (Kholif *et al.,* 2016). With regard to leaf production, the leaf fresh weight yield of the plant is 1–5 kg per tree annually. This value is equivalent to 10,000–50,000 kg/ha annually at 1 m × 1 m spacing (Sánchez *et al.,* 2006). In a 10 cm × 10 cm spacing, leaf yield is 7–8 kg/m^2 at the first cutting in well-irrigated, drained, and fertilized beds, with up to seven cuttings a year (Wu *et al.,* 2013). Although this intensive farming pattern can yield high amounts of leaves in a small area, it is unsuitable for large-scale plantation due to the large quantity of seeds required. A row spacing of 0.75 m × 1 m is the best cultivated pattern for leaf production in a large farming area (Foidl *et al.,* 2001). Plantations for leaf production can also be integrated in agroforestry systems with spacing distance of 2-4 m between rows, harvest interval around 60 days, fertilization and irrigation are not necessary (Leone *et al.*, 2015). Biomass yields vary widely depending on farming conditions, including variety, soil type, climate, fertilization, and irrigation system. In practice, the best harvest can be obtained under warm and dry conditions and regular fertilizer supplement and irrigation (Dania *et al.,* 2014).

The species is resistant to most pests and diseases, but outbreaks may occur under certain conditions. For example, diplodia root rot may appear in waterlogged soils, causing severe wilting and death of plants (Palada and Chang, 2003). Mite populations can increase during dry and cool weather. These pests induce yellowing of leaves, but plants usually recover during warm weather. Other insect pests include termites, aphids, leaf miners, whiteflies, and caterpillars (Palada and Chang, 2003). Chemical control of insect pests should be used only when severe infestations occur. Choose a pesticide that targets the specific pest causing the damage, and avoid pesticides that kill or inhibit the development of beneficial organisms.

Livestock feed and fodder

Moringa has a long history as a feed ingredient for ruminants and non-ruminants. As a feed ingredient almost all parts are used as feed ingredients, such as seeds, fresh leaves, young twigs, and waste of moringa seed oil extraction. Currently, its leaves have attracted the most attention of ruminant nutritionists as a source of protein because of its optimal balance of amino acid composition and easily digestible protein content (Babiker *et al.,* 2017). This plant has the potential to supplement low-quality livestock fodders thereby increasing dry matter intake (DMI) and digestibility. It serves as the best example of quality fodder for increasing milk and meat production along with its environment friendly nature and low input requirements. The green fodder as well as dry matter (DM) production depends on the fertilizer, genetic makeup, season and ecological conditions (Palada *et al.,* 2007). Macronutrients which are present in abundance in moringa play important roles like tissue building, physiological, metabolic, and biochemical processes in livestock. Magnesium (Mg) and Potassium (K) also present in sufficient quantity are important for lactating animals. Besides essential nutrients and multivitamins, moringa leaves also possess crude protein (21.8%), acid detergent fibre (22.8%), and neutral detergent fibre (30.8%). The crude fat (412.0 g/kg), carbohydrates (211.2 g/kg) and ash (44.3 g/kg) have also been reported in its leaves (Oliveira *et al.,* 1999). All these compounds are important in increasing livestock production. Hence, moringa leaves which are rich source of these nutrients; fulfill the nutritional requirements of livestock in the best possible way.

Various studies have shown a positive effect of giving moringa leaves in various forms when given as non-ruminant feed, such as poultry, fish, and rabbits as well as ruminants (Wu *et al.,* 2013; Selim *et al.,* 2021). However, moringa cannot be used as the sole feed for ruminants because it contains various kinds of anti-nutrients, which may negatively affect the development of ruminants. Inappropriate feeding may harm overall livestock performance or not affect it at all on livestock performance. The anti-nutritional content contained in this plant can have positive or negative impacts when given as animal feed. The anti-nutritional content found in the moringa plant includes tannins, sterols, terpenoids, flavonoids, saponins, anthraquinones, alkaloids, glucosinolates, isothiocyanates, glycoside compounds and glycerol-1-9-octadecanoic (Al-Taweel *et al.,* 2019; Jattan et. al., 2021). The study by Auwal *et al.* (2019) showed that moringa contains various kinds of anti-nutrients such as phytate 10.58 ± 0.01 (mg/100g), oxalate 334.33 ± 0.67 (mg/100g), tannins 8.19 ± 0.01 (mg / 100g), alkaloids 1.72 ± 0.01% and HCN 3998.30 ± 0.49 (mg/100g). Research by Su and Chen (2020) shows that anti-nutritional factors can interact with the chemical composition of feed, disrupting digestive or metabolic processes in the body with various mechanisms and can result in effects contrary to optimal utilization of nutrients. However, research on the negative effects of giving negative effects had not revealed much, or they may have shown no negative effects that are quite severe as a result of giving moringa. The results of Zaher *et al.* (2020) also showed that giving moringa leaves 75% and 100% as a substitute for concentrates would reduce the final body weight and ADG. However, Olvera-Aguirre *et al.* (2020) showed that dietary supplementation of moringa leaf hydroalcoholic extract at a dose of 40 or 60 mL/ sheep/day in lactating sheep had no impact on milk production. The results of the research by Babeker and Abdalbagi (2015) showed that giving concentrate containing 20% moringa leaf meal is the optimal amount in increasing the performance of goats when compared to 50 percent. Moringa can be mixed or replaced with other feed ingredients with various feed ingredients such as soybean meal (Abdel –Raheem and Hassan, 2021), corn silage (El-Esawy *et al.,* 2018), alfalfa hay (Dong *et al.,* 2019) and cottonseed flour (Zhang *et al.,* 2018). In addition, being a protein source feed, moringa also has a lot of anti-nutritional content, which is useful for treating various diseases in livestock, both non-ruminants and ruminants. It contains various phytochemicals, which are very beneficial for livestock health.

Climate change mitigation

Moringa has vital potential to sequester more atmospheric carbon dioxide (Gedefaw, 2015). This plant produces high biomass even during the dry season and acts as a good sink for carbon dioxide, thus reducing the level of carbon dioxide in the atmosphere, which is one of the main causes of ozone layer depletion and global warming (Daba, 2016). An early report showed that the capacity of the moringa tree to absorb carbon dioxide is 50 times higher than that of the Japanese cedar tree (*Cryptomeria japonica*) and twenty times higher than that of general vegetation (Trigo, *et al.,* 2021). Further, Mabapa *et al.* (2018) conducted study to determine the potential of three drought-tolerant tree species (*Moringa oleifera, Colophospermum mopane,* and *Sclerocarya birrea*) to mitigate climate change through carbon sequestration under semiarid conditions, showed that moringa was among the species with the highest capacity for carbon sequestration.

The replacement of soybean meal with

moringa leaf meal decreased CH_4 production in goats and steers (Elghandour *et al.,* 2017). Other results asserted that the use of moringa supplementation in the diet of dairy cows not only improved dairy production (milk yield) and quality of milk but also helped to regulate the microbial metabolic function and methane emissions (Dong *et al.,* 2019). In in-vitro study, rumen emissions were significantly reduced when leaves or extracts of moringa were used, through active modulation of the rumen microbiome (Ebeid *et al.,* 2020). Lins *et al.* (2019) examined the effects of increasing concentrations of raw, ground moringa seeds on rumen fermentation and CH_4 production, using the rumen stimulation technique (Rusitec). The results of this study showed that methane production linearly decreased as the inclusion of moringa seeds increased (0, 100, 200, and 400 g/kg concentrate dry matter). Increasing moringa by 1 g/kg DM decreased CH_4 emission by 6 g/kg gain and absorbed nitrogen loss by 0.069%, possibly due to improved energy efficiency (Sultana *et al.,* 2021). Using moringa extract as feed supplement reduced CH_4 and CO_2 production in goats (Pedraza-Hernandez *et al.,* 2019). Further studies provided evidence that moringa can help to mitigate methane emissions in cattle (Mangar *et al.,* 2022). Additionally, other results showed that feeding lambs moringa root bark reduced the estimated CH_4 produced per unit of body weight gain (Soltan *et al.,* 2019). Supplementing diets with alternative protein sources from trees and shrubs increased the dry matter intake and improved microbial protein synthesis in the rumen and the efficiency of rumen fermentation, with a shift in fermentation towards propionate (Halmemies-Beauchet-Filleau *et al.,* 2018). The Recent study by Kholif *et al.* (2023) showed that replacing a concentrate feed mixture with up to 30% moringa silage positively impacted the ruminal fermentation, with an inhibition of CH_4 production.

CONCLUSION

Tree fodders serve as a livelihood support to farmers with their regular supply of nutritive green fodder throughout the year, their rugged-ness to survive in harsh climates, and faster growth rates. In present day context, moringa is a good alternative for substituting commercial rations for livestock. The relative ease with which moringa can be propagated through both sexual and asexual means, and its low demand of soil nutrients and water after being planted, make its production and management comparatively easy and particularly promising, especially in Third World countries. Its high nutritional quality and better biomass production, especially in dry periods, support its significance as livestock fodder. Due to its high content of nutrients, especially proteins and bioactive compounds, it can be used as an alternative to conventional ruminant feed materials. Various results showed that using moringa either individually or in combination with other feedstuff improved the production performance (growth rate, milk yield, and milk quality) in cattle, sheep, and goats. All parts of moringa can sequester more atmospheric carbon dioxide, and, by feeding it to ruminants, can also reduce rumen methane emissions. This indicates that this plant can be successfully grown in agroforestry systems, which can supply animals with high value feed supplements and contribute to the adaptation and mitigation of climate change. Finally, future research should focus on the effects of different supplements of moringa feed and extracts (leaves, seeds, flowers, roots, and bark) on livestock performance and CH_4 emission.

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