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Potential of *Moringa oleifera* L. as livestock fodder crop: a review

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Abstract: Dairy and meat production in dry regions is very complex due to low quality and shortage of fodder, especially in dry periods. Livestock scientists are eager to explore and investigate good-quality fodders that can boost milk and meat production in an organic and economical way. Some organic meals like soybean, cotton seed cake, and range grasses are being utilized to overcome the fodder shortage. These have some limitations, however, like unavailability in December through May as currently green fodder is least available after wheat, alfalfa, brassica, and maize harvesting. This leads towards reduced livestock production and low-quality milk and meat products. At the same time, the rapid increase in human population is increasing the food requirements, which is in turn threatening environmental conservation and enlarging the gap between the availability of resources and the meeting of human necessities. People are fulfilling their requirements for food and shelter by depleting natural resources. Plant scientists are exploring the types of plants that can fulfill the life necessities of both human beings and livestock but can also be used as growth enhancers for main crops without natural resources degradation. Over the last few years, underutilized crops and trees have captured the attention of plant scientists, nutritionists, and growers. *Moringa oleifera* 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. The present review article gives a detailed discussion on the nutritional quality of moringa parts and their palatability for livestock, fish, and poultry, as well as suitable growing conditions and cultural practices.

Key words: Antinutritional factors, livestock fodder, moringa, nutritional quality

1. Introduction

Globally, agriculture plays a key role in improving livelihood, especially in rural communities. Livestock is the main stay of agricultural community. It provides 50% of the value of agricultural output globally and one-third in developing countries. During the past 3 decades, rapid increase and development in the livestock sector has led to "livestock revolution" or "food revolution" due to rapid technology invasion in this sector, and especially improvement in the poultry industry. This increase in livestock production has emerged to be more impressive than cereal production of green revolution, as reflected by increases of 331% in egg production, 127% in meat production, and 113% in fish production against only a 78% increase in cereal production (Sansoucy 1995). Delgado et al. (1999) and van Rooyen (2008) reported livestock as the biggest land-use activity globally, which is said to be doubled by 2020 with an annual increase of 2.7% and 3.2% in meat and milk production, respectively. Developed countries are contributing almost 80% of the world's total milk production while contributing only one-third of the world's cattle population with the rest of the population existing in developing countries sharing only 20% of total milk production (Tahir 2005). The Food and Agriculture Organization of the United Nations (FAO 2009) reported the total world population of buffaloes (188.3 million), cattle (1382.2 million), chickens (18,554.8 million), goats (868.0 million), and sheep (1071.3 million), but this livestock population still cannot fulfill consumers' requirements.

Livestock population in Pakistan has boosted up to 167.5 million heads, which is contributing 51.1% in

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an agriculture economy; that is more than the crops' share (41.9%) to the agricultural sector and 11.5% to the national GDP (Government of Pakistan 2012). Out of this substantial contribution, almost 90% of milk is produced by small farmers or landless livestock farmers, who maintain 87% of livestock heads on their small farmlands and in backyards (Rabbani 2008). On the other hand, the availability of cultivated green fodder has decreased due to reduction in cultivatable area for fodder production (Sarwar et al. 2002). Currently, farmers are focusing only on cash crops instead of fodder or forage production due to less income return. The cultivatable fodder area (3.35×10^6 ha) is continuously being depleted at 2% every 10 years (Gill 1998). This decline results in low quantity and quality of fodders, which is responsible for poor livestock production. The rangelands of Pakistan contribute 38% of the nutritional requirements of livestock in Pakistan (Hanjra et al. 1995; Sarwar et al. 2002; Qadir 2009). Various researchers have reported severe shortage in total digestible nutrients (TDNs) (29%–39.41%) and digestible crude protein (DCP) (56.5%–56.6%) for livestock (Crowder 1988; Khan et al. 1988). Akram (1990) reported a 25% shortage of TDN and a 40% shortage of DCP. Current estimates of deficient nutrients to livestock are 48.58×10^6 t of TDN and 6.99×10^6 t of DCP (Government of Pakistan 2008). These estimates were based on a livestock census of Pakistan conducted in 2006. This fodder shortage gets increased in dry months (May and October) when the unavailability of fodders increase (Sarwar et al. 2002). 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. For example, poplar and willow, *Acacia albida*, *Prosopis*, and *Gleditsia*, are being used as fodder trees in New Zealand, Africa, and South Africa, respectively (Graham and Dalmeny 1998). These have been used for multiple purposes, such as food, shelter, wood- or nonwood-based products, oil, biodiesel, or medicines. However, it is very difficult to get all these benefits just from one plant or system. Plant scientists are focusing their work on tree species that can provide good-quality fodder especially in dry periods when no other fodder is available. Tree species like *Leucaena leucocephala*, *Ziziphus jujuba*, *Morus alba*, *Terminalia arjuna*, and *Moringa oleifera* are being widely studied nowadays. *M. oleifera* is a remarkable species with its high nutritional value and good biomass production, which can be used as a nutritional supplement (Sanchez et al. 2006). As discussed above, scientists are now looking for the availability of fodder trees that are good for their nutritional value and are available throughout the year, especially during dry months. The present review article encompasses the potential of *M. oleifera* as a possible valuable resource for livestock fodder by analyzing its strengths and weaknesses. The nutritional qualities and harmful compounds of moringa leaves and seeds, as well as its prospective as livestock fodder, will also be discussed.

2. Natural history, range, and growing conditions of moringa

M. oleifera belongs to the monogeneric family Moringaceae, which includes another 12 species of shrubs and trees (Verdcourt 1985; Olson 2002). The family Moringaceae includes species exhibiting a wide range of forms, from bottle trees to slender trees, sarcorhizal trees, or tuberous shrubs (Olson and Carlquist 2001). All these species are native to the Indian subcontinent, the Red Sea area, and parts of Africa, including Madagascar. Although moringa is native to India and Pakistan (Verdcourt 1985; Morton 1991; Duke 2001), it is widely cultivated, especially in dry tropical areas of the Middle East and Africa (Fahey 2005; Palada et al. 2007; Nouman et al. 2013) and more recently in many countries located within the tropics, like Nicaragua, because its pods, seeds, leaves, and roots are useful as fodder, vegetable, and plant growth enhancers (Kantharajah and Dodd 1991; Veeraragava 1998; Mughal et al. 1999; Anhwange et al. 2004, Sanchez et al. 2006; Nouman et al. 2012a, 2012b, 2013). Besides being consumed by humans, (Bennett et al. 2003; Gidamis et al. 2003), it is also used as animal fodder (Sanchez et al. 2006; Nouman et al. 2013), a natural coagulant of turbid water (Suarez et al. 2003), and a source of phytomedical compounds (Anwar et al. 2006).

Moringa is a drought tolerant plant that can be grown in diverse soils, except those that are waterlogged. Slightly alkaline clay and sandy loam soils are considered the best media for this species due to their good drainage (Ramchandran et al. 1980; Abdul 2007). *M. oleifera* does not grow properly under waterlogged conditions as its roots get rotten (authors' personal observation). This species can tolerate water with an electrical conductivity (EC) of 3 dS m^{-1} during its germination phase, while at later stages its resistance to saline water increases (Oliveira et al. 2009). Once it has established itself, its strong antioxidant system helps it to cope with moderate saline conditions (EC: 8 dS m^{-1}), experiencing only a mild reduction in its mineral quality (Nouman et al. 2012b).

Thus, moringa can be grown in versatile conditions including hot, humid, dry tropical, and subtropical regions, except for waterlogged conditions. It can perform better under marginal conditions with ample nutritional quality.

3. Moringa as fodder for livestock

Various research reports and reviews have highlighted the importance of trees and shrubs being used as livestock fodder or in supplementing the low-value fodders or rations in the dry season (Atta-Krah 1990; Lefroy et al. 1992; Otsyina and Dzowela 1995). As mentioned previously, the moringa leaves, fresh pods, seeds, and roots are being widely and increasingly used by humans and animals because of their higher contents of essential nutrients (CSIR 1962; Hartwell 1971). Scientists devoted to livestock research, however, are not only interested in finding good-quality fodders that can increase milk and meat production, but they are also looking for species that can be grown and exploited in environmentally friendly ways and cultivated inexpensively. Such demands are also met by moringa.

Researchers (Richter et al. 2003; Sanchez et al. 2006; Mendieta-Araica et al. 2011) have explored moringa cultivation practices and its utilization as livestock fodder and in fish diet. They have shown that this species has potential as livestock fodder. Moringa trees are used for diverse purposes because they are easy to maintain once their roots have developed and established (moringa trees have a deep tap root system when they are grown from seeds, and an adventitious root system when they are grown from stem cuttings). Its roots penetrate deep into soil to search for water and nutrients, which enables moringa trees to tolerate severe conditions. Aside from the features of its root system, this species has a fast growing habit, a low requirement of maintenance in late stages, reduced necessity of fertilizers and irrigation, and a high capacity to resprout after harvesting. Relatively low requirements for irrigation makes moringa superior to some other livestock meals like soybean, cotton seed cake, and range grasses, which require relatively high irrigation to avoid reduced livestock production (Benavides 1994). Soybean, for instance, requires intensive irrigation, which makes it too difficult to cultivate for small livestock farmers.

Moringa crop produces high dry matter (DM), between 4.2 and 8.3 t ha^{-1}, depending on the fertilizer, accession, season, and ecological zone (Palada et al. 2007). Foidl et al. (2001) carried out a moringa biomass production project and tested different planting densities to get maximum biomass values. They found that at higher planting densities, more biomass can be achieved. Goss (2012) also reported similar findings, stating that dry biomass (above and below ground) of moringa plants increased when plant density was increased from 49,384 plants ha^{-1} to 197,528 plants ha^{-1}. The researchers argued that the plants at higher planting densities efficiently compete with each other for more resources, which results in root elongation and expansion (Squire, 1990), but this does not always happen. Damtew et al. (2011) also found increasing biomass production and leaf area index of *Artemisia annuna* when it was planted at higher planting density. Foidl et al. (2001) also reported that higher planting densities (>1,000,000 ha^{-1}) are difficult to maintain due to laborious harvesting procedures. Thus, the best approach is to maintain the planting density at efficient and optimum levels to utilize the resources in a good way according to environmental conditions (Sadeghi et al. 2009). At initial levels, the seed sowing rate of *M. oleifera* can be greater to avoid plants' mortality effects, but later on, optimum planting density might give more biomass and is also easier to maintain. The optimum planting density (250,000 plants ha^{-1}) for moringa crop was reported by Sanchez et al. (2006), which gave 80,200 and 17,600 kg ha^{-1} fresh and dry biomass per year, respectively (Table 1) under Nicaraguan conditions. Harvesting was carried out every 40–75 days, but this varies (Newton et al. 2006; Sanchez et al. 2006). This wide range of cutting frequencies (40–75 days) is due to differences in the climatic conditions in which moringa is grown. In Ghana, maximum biomass production was obtained when moringa leaves were harvested after 40 days (Newton et al. 2006). In Nicaragua, Sanchez et al. (2006) reported that the maximum moringa fresh and dry biomass (100,700 and 24,700 kg ha^{-1}, respectively) can be obtained using a cutting frequency of 75 days during the first year of the experiment (Table 1). The highest biomass of moringa crop was obtained when moringa plants were planted in narrow spacing (5 × 15 cm) because the number of leaves produced per plant increased with time (Newton et al. 2006). Moreover, Newton et al. (2006) also reported that moringa plants gave higher yields when harvested at cutting intervals of 35–40 days, while Sanchez et al. (2006) reported that higher biomass can be achieved when the moringa crop was harvested at a 75-day cutting interval. The difference between the findings of these researchers might be due to different climatic conditions of the study sites. A few experiments conducted on different fodder trees like *Leucaena leucocephala*, *Ziziphus jujuba*, and *Morus alba* also showed that longer cutting intervals gave better leaf yield in comparison to shorter cutting intervals (Barnes 1999; Latt et al. 2000; Tuwei et al. 2003). The reduced yield at shorter cutting intervals of plants might be due to the reduction in nutrient assimilation, which affects the growth rate of plants by affecting the leaf development (Latt et al. 2000). It is suggested to keep suitable cutting intervals for plant regeneration and to absorb the cutting shock (Assefa 1998). In Pakistan, the optimal cutting frequency was 30 days, except in winter (Nouman 2013). These findings show that moringa plants are highly adaptable and exhibit a remarkable plasticity in response to environmental conditions related to the cutting frequencies.

Moringa leaves are rich in nutrients like iron, potassium, calcium, and multivitamins, which are essential for livestock weight gaining and milk production

Table 1. Moringa biomass production as fodder crop on various planting densities and cutting frequencies.

Planting density (plants ha^{-1})	Fresh biomass (kg ha^{-1})		Dry biomass (kg ha^{-1})		References
	1st year	2nd year	1st year	2nd year	
95,000	19,600		33,300		Foidl et al. 2001
350,000	29,700		50,500		
900,000	52,600		89,400		
1,000,000	78,000		132,600		
4,000,000*	97,400		165,600		
16,000,000*	25,900		440,300		
250,000	80,200	41,100	17,600	7600	Sanchez et al. 2006
500,000	79,100	46,200	16,900	8100	
750,000	88,000	36,100	18,900	6200	
Cutting frequency (days)	1st year	2nd year	1st year	2nd year	
45	71,400	26,700	13,500	4700	Sanchez et al. 2006
60	75,300	39,400	15,200	6800	
75	100,700	54,700	24,700	10,400	

*: Test plots with higher planting densities.

(Newton et al. 2010; Mendieta-Araica et al. 2011). Moringa leaves also contain 21.8% crude protein (CP), 22.8% acid detergent fiber (ADF), and 30.8% neutral detergent fiber (NDF), as well as 412.0 g kg^{-1} of crude fat, 211.2 g kg^{-1} of carbohydrates, and 44.3 g kg^{-1} of ash (Oliveira et al. 1999; Sanchez et al. 2006). All these compounds are useful to increase livestock production. Moreover, low-quality livestock fodders or rations can be improved by adding moringa leaves as a supplement, which increases the dry matter intake (DMI) and the digestibility of the fodder by livestock, as well as increasing the protein intake in fish diet (Richter et al. 2003). Moringa leaves mixed with 20% and 50% batiki grass can improve DMI, constituting a mixture with high digestibility of DM and CP, and low NDF value (Tuwei et al. 2003). Moringa leaves are also a good protein source that is a convenient substitute of soybean and rapeseed meals for ruminants, and they are able to improve the microbial protein synthesis in the rumen (Soliva et al. 2005).

Different mixtures composed by different parts of moringa plants have different nutritional value (Table 2). It is reported that moringa fodder leaves have higher CP contents (21.87%) than moringa tree leaves (23.51%) (unpublished data). Similarly, lower NDF and ADF contents were recorded in moringa fodder leaves, which show better fodder quality (Table 2). Thus, the mixtures with different proportions of moringa leaves, twigs, or branches have different CP and NDF contents (Aregheore 2002). The mixture of moringa leaf meal with soft twigs have lower CP and higher NDF contents, while moringa leaves with seed cake have higher CP contents (Murro et al. 2003; Fujihara et al. 2005). Depending upon the quality of different moringa fractions, the farmers can decide which animals can utilize these fractions in the best way. For example, low CP meals (moringa leaves with twigs) can be easily consumed by dry cows, which require low nutrients' fodders.

Moringa oleifera has been a focus of scientists for its quality to be utilized as livestock fodder. Less importance has been given to other species belonging to the family Moringaceae. A few researchers have evaluated the potential of *Moringa stenopetala* as livestock fodder (Abuye et al. 2003; Jiru et al. 2006; Gebregiorgis et al. 2012). It is reported that *M. stenopetala* leaves have high CP contents (9% of DM), 280 mg kg^{-1} of vitamin C, and 160 mg kg^{-1} of β-carotene contents with iron and calcium contents of 30.8 and 7928 mg kg^{-1}, respectively (Abuye et al. 2003). 'Gamolle', an accession of *M. stenopetala*, gave higher biomass yield than *M. oleifera* (Jiru et al. 2006). It was reported that *M. oleifera* has more leaves than *M. stenopetala*, as researchers had observed that the leaf and twigs ratio was 2.3:1 in *M. oleifera* while it was 1.5:1 for *M. stenopetala*. No doubt, *M. stenopetala* leaves can also be used as livestock fodder due to its good nutritional value, but *M. oleifera* has a few advantages. In the case of leaf-twigs index, *M. oleifera* had only 5% twigs while *M. stenopetala* had 7.4%, which showed low leaf biomass in the latter case. Chemical analysis of leaves of both species revealed that CP in *M. stenopetala* (26.91%) was higher than in *M. oleifera* (22.21%), but calcium contents were

Table 2. Comparative analysis (%) of fodder quality of stem and leaves of moringa as tree and fodder crop.

Moringa farts/fractions	DM	CP	EE	CF	Ash	NDF	ADF
Moringa fodder leaves	7.8	21.87	6.5	4.5	12	8	6
Moringa fodder stem	8.0	8.75	2	20	12.5	28	21
Moringa fodder leaves and stem	7.6	15.31	3	14.5	12	16	12
Moringa tree leaves	8.6	23.51	3	7.5	13.5	11	6
Moringa tree stem	8.6	10.93	1	26.5	10.5	36	26
Moringa tree leaves and stem	9.2	16.41	2.5	17.5	11	21	15

DM = dry matter; CP = crude protein; EE = ether extract; CF = crude fiber; NDF = neutral detergent fiber; ADF = acid detergent fiber.

higher in *M. oleifera* leaves (2.5%) in comparison with leaves of *M. stenopetala* (1.5%). Moreover, it was also reported that the mixing of *M. stenopetala* leaves with Rhodes grass improved DMI, body weight, and nitrogen retention capacity in male sheep (Gebregiorgis et al. 2012). Many flavonoids have also been reported in both *M. oleifera* and *M. stenopetala*, but no work has been done on other moringa species (Bennett et al. 2003; Siddhuraju and Becker 2003; Lako et al. 2007; Manguro and Lemmen 2007). These findings prompt plant and animal scientists to expand the moringa research to other Moringaceae species.

Macronutrients like P, K, Ca, and Mg play key roles in building tissues and balancing the physiological, metabolic, and biochemical processes of livestock. Mg deficiency in cows makes them suffer from low blood Mg during lactation, which causes low milk yield. During lactation, 0.17%–0.20% Mg in dry matter is required for cows (NRC 1996). Similarly, K is required for lactating animals. Beef cows require 0.70% K in dry matter during lactation. Moringa leaves contain 20,718 and 106.3 mg kg^{-1} of macronutrients Mg and K, respectively. Hence, moringa leaves fulfill the dietary and nutritional requirements of livestock animals. Moreover, the mixing of moringa leaves with other fodders or grasses can also contribute towards better livestock performance and high yield of good-quality products.

By reviewing the above-mentioned reports and findings, it can safely be suggested here that moringa leaves are useful supplements for livestock that not only increase the output of products, but also their quality. In dry months, when no other fodder is available and the fodder quality is diminished due to harsh and severe climatic conditions, moringa leaves can be used as a substitute for commercial rations.

4. Nutritional value of moringa

A prolonged and good-quality food supply is essential for the development of any stable community. People should be able to fulfill their nutritional requirements consuming vegetables, fruits, cereals, meat, and milk, but many of these products are not affordable for a great number of persons, especially those who live below the poverty line. Therefore, in the communities constituted by poor or extremely poor people, plants that are particularly nutritious are valuable members of the available spectrum of plants. Moringa seems to have the potential for solving, at least partially, many of the needs of the members of such communities and could play an important role in sustainable communities due to its high nutritious quality and adaptability to diverse and challenging environments.

The nutritional value and composition have been strongly emphasized in the literature for different trees and shrubs to expose their importance for livestock (D'Mello and Devendra 1995). The recommendation of trees, shrubs, or fodder crops is based on proximate analysis including crude protein, crude fiber, ash mineral contents, etc. Their high protein content is one of the most cited advantages of moringa leaves. For example, they contain 9 times more protein than yoghurt does, as is repeatedly mentioned in the literature (Mathur 2006). In various reports (Stelwagen 2003; Chandan 2006), it has been reported that cow, buffalo, goat, and sheep milks provide average CP contents of 3.4%, 4.7%, 4.1%, and 6.3%, respectively, while fresh and dry moringa leaves exhibit CP contents of 67.0 and 271.0 g kg^{-1}, respectively. Likewise, Mendieta-Araica et al. (2011) reported 292 g kg^{-1} CP contents in moringa leaves, while Soliva et al. (2005) and Ferreira et al. (2008) reported 332.5 g kg^{-1} (value derived from the findings of Oliveira et al. 1999; Abdulkarim et al. 2005). These comparisons confirm that moringa leaves contain higher amounts of CP in comparison with milk. Moreover, Minson (1990) and Soliva et al. (2005) reported that CP contents in raw and extracted moringa leaves are 47% and 64% higher, respectively, than those of common forages and grasses consumed by livestock. As is evident from these reports that moringa leaves are a rich protein source (Thurber and Fahey 2009), they can be used by physicians, nutritionists, and members of the health community to solve the malnutrition problem, especially in Third World and developing countries. Moreover, this statement seems reasonable in light of the fact that 1 tablespoon of moringa leaf powder contains 9.9%–13.6% of the daily CP requirement of children and breast-feeding mothers.

It has also been reported that the amino acid profile of moringa leaves meets the standards of the World Health Organization (WHO). Moringa leaves have higher amounts of all amino acids than are required for children, according to FAO reference protein levels (Makkar and Becker 1996). Methionine and cysteine contents in raw moringa leaves and extracted moringa leaves are 14.14 and 8.36 mg g^{-1} of DMI, respectively (Table 3), while nonfat dry milk and dry whole milk contain 12.41 and 9.03 mg g^{-1} (methionine + cysteine), respectively (Table 3), which are less than levels in moringa raw and extracted leaves. Block and Mitchell (1946) introduced the concept that the nutritional quality of protein can be assessed based on the amino acid contents, which was further refined by Pellett and Young (1980). Table 3 shows the values of amino acid contents in raw and extracted moringa leaves in comparison with nonfat dry milk and dry whole milk. Young and Pellet (1994) and Gopalan et al. (1996) reported that plant foods, especially cereal crops, have low lysine contents, while legumes show higher amounts. Moreover, they also reported that better lysine contents are being provided by livestock products, like milk. However, in the case of raw and extracted moringa leaves, it is clear from various studies (Makkar and Becker 1996, 1997; Fuglie 1999, 2000; Foidl et al. 2001; Ferreira et al. 2008; Newton et al. 2010; Mendieta-Araica et al. 2011) that these are also a very good source of all amino acids, including lysine. Table 3 illustrates that moringa leaves exhibit a good amino acid score compared with milk and can fulfill the daily requirements of adults. Moringa seed meal also has good amounts of all the amino acids, except for valine, lysine, and threonine (Oliveira et al. 1999), and also have 43.6 g kg^{-1} of protein of methionine + cysteine, which is very close to that of human milk, chicken eggs, and cow milk. Moreover, moringa dry leaves and fresh pods are also a good source of amino acids (Table 4). Arginine, valine, and leucine contents were found higher in moringa dry leaves and fresh pods, while serine, glutamate, aspartate, proline, glycine, and alanine could not be detected in these moringa parts (CSIR 1962; Freiberger et al. 1998; Fuglie 2000).

Table 3. Comparison of amino acid contents in moringa leaves, human milk, and cow milk, along with the daily amounts recommended by FAO (Zarkadas et al. 1995; Makkar and Becker 1996, 1997; Fuglie 1999, 2000; Foidl et al. 2001; FAO/WHO/UNU 2007; Ferreira et al. 2008).

Amino acid	Raw moringa leaves (mg g^{-1} DM)	Extracted moringa leaves (mg g^{-1} DM)	Nonfat dry milk (mg g^{-1})	Dry whole milk (mg g^{-1})	Daily requirement for adults (mg/kg)
Lysine	26.77	14.06	28.68	20.87	30
Leucine	42.89	21.84	35.42	25.78	39
Isoleucine	22.53	11.30	21.88	11.88	20
Methionine	8.96	4.97	9.07	6.60	15
Cystine	5.18	3.39	3.34	2.43	
Phenylalanine	27.14	15.51	17.46	12.71	25
Tyrosine	18.88	9.71	17.46	12.71	
Valine	27.58	14.26	24.20	17.62	26
Histidine	13.57	7.50	9.81	7.14	10
Threonine	21.97	11.70	16.32	11.88	15
Serine	20.79	10.34	19.67	14.32	nd
Glutamic acid	50.85	25.65	75.72	55.12	nd
Aspartic acid	46.11	22.16	27.43	19.97	nd
Proline	25.75	13.63	35.03	25.49	nd
Glycine	26.62	13.73	7.650	5.570	nd
Alanine	28.67	18.37	12.47	90.80	nd
Arginine	30.28	15.64	13.09	95.30	nd
Tryptophan	9.26	5.27	5.10	3.71	4

nd = nondetectable.

Table 4. Comparison of amino acid contents in moringa dry leaves and fresh pods.

Amino acid	Dry leaves (mg 100 g^{-1} N)	Pods (mg 100 g^{-1} N)	References
Lysine	1125	150	Freiberger et al. 1998; Fuglie 2000
Leucine	1950	650	Fuglie 2000
Isoleucine	825	440	Fuglie 2000
Methionine	350	140	Fuglie 2000
Cystine	nd	nd	
Phenylalanine	1388	430	Fuglie 2000
Tyrosine	nd	Nd	
Valine	1063	540	Fuglie 2000
Histidine	613	110	Freiberger et al. 1998; Fuglie 2000
Threonine	1188	390	Fuglie 2000
Serine	nd	nd	
Glutamate	nd	nd	
Aspartate	nd	nd	
Proline	nd	nd	
Glycine	nd	nd	
Alanine	nd	nd	
Arginine	1325	360	Fuglie 2000
Tryptophan	425	80	Freiberger et al. 1998; Fuglie 2000

nd = nondetectable.

In addition, it has been reported that total carotenoids' mean concentration is 40,139 µg 100 g^{-1} of fresh weight in moringa leaves, out of which 47.8% (19,210 g kg^{-1}) corresponded to β-carotene (Seshadri and Nambiar 2003). Moringa leaves contain 379.83 mg kg^{-1} iron, 18,747.14 mg kg^{-1} calcium, 1121 mg kg^{-1} phosphorous, 22.05 mg kg^{-1} zinc, and 20.5 mg kg^{-1} crude fiber on dry matter basis (Table 5) (Makkar and Becker 1997; Fuglie 1999, 2000; Foidl et al. 2001, Nouman et al. 2012a). Moreover, moringa leaves are also a good source of oxalic acid contents (11.2 mg g^{-1}), which are not harmful to the immune system (Makkar and Becker 1997). Iron and zinc elements are said to act as a brain activator. It has been repeatedly found in the literature that moringa leaves contain 25 times more iron than spinach (Mathur 2006). Spinach leaves have good iron quantity but its absorption is very limited, while in moringa leaves the absorption level is better than in other leafy vegetables. Iron in the presence of zinc activates the brain more sharply. Moreover, the high concentrations of these elements or compounds are relevant because it has been reported that about 2 billion people worldwide, especially in developing countries, have deficiencies of some of these nutrients, mainly of vitamin A and Fe (Rweyemamu 2006). Moreover, moringa fresh pods also considered as a rich source of Ca (1248 mg kg^{-1}), P (1757 mg kg^{-1}), K (15416 mg kg^{-1}), and Na (1709 mg kg^{-1}) (Table 6). Researchers and nutritionists have reported these moringa parts as beneficial nutritional supplements for livestock improving their nourishment and metabolic activities (Foidl et al. 2001; Newton et al. 2010).

5. Harmful compounds in moringa

Antinutritional factors are defined as substances generated in natural food items by the normal metabolism of species and by different mechanisms that exert an effect opposite to optimum nutrition (Kumar 1992). Many grain legumes from which leaves are used as livestock fodder or feed contain antinutritional factors like protease inhibitors, lectins, saponins, or trypsin. Mostly, these antinutritional factors are disliked by livestock animals due to bitter taste, poor palatability, and indigestibility. The fodder trees are not an exception from these antinutritional factors. Therefore, many fodder trees are not selected as the first option for livestock production due to the presence of harmful compounds in leaves and other palatable parts. Antinutritional factors present in legumes may cause health problems and may be fatal for the consumers (livestock or human beings). It is said that when the nutritious supply of livestock fodder is insufficient, then trees are the only source for farmers to feed their livestock.

Table 5. Mineral contents in moringa leaves.

Nutritional contents	Moringa leaves (mg kg^{-1})	References
Calcium	18,747.14	Aykroyd 1966; Freiberger et al. 1998; Fuglie 2000; Foidl et al. 2001; Yang et al. 2006; Nouman et al. 2012a
Phosphorous	1121	Freiberger et al. 1998; Fuglie 2000; Nouman et al. 2012a
Magnesium	106.2	Aykroyd 1966; Freiberger et al. 1998; Foidl et al. 2001; Fuglie 2001; Nouman et al. 2012a
Sodium	2241.17	Freiberger et al. 1998; Foidl et al. 2001; Nouman et al. 2012b
Potassium	20,718.5	Makkar and Becker 1996, 1997; Fuglie 1999, 2000; Foidl et al. 2001; Newton et al. 2010; Nouman et al. 2012a
Iron	379.83	Aykroyd 1966; Freiberger et al. 1998; Fuglie 2000; Rweyemamu 2006; Yang et al. 2006
Manganese	83.37	Freiberger et al. 1998; Foidl et al. 2001
Zinc	22.05	Freiberger et al. 1998; Foidl et al. 2001
Copper	9.483	Aykroyd 1966; Freiberger et al. 1998; Fuglie 2000; Foidl et al. 2001
Sulfur	1370.0	Aykroyd 1966; Foidl et al. 2001; Fuglie 2000
Chromium	<5	Freiberger et al. 1998
Molybdenum	7.45	Freiberger et al. 1998
Nickel	<5	Freiberger et al. 1998
Selenium	27.12	Freiberger et al. 1998; Newton et al. 2010

Particularly in dry seasons, the usage of tannin-containing feedstuff is preferred, especially in developing countries, but such feedstuff can be toxic or fatal for livestock animals. Thus, the utilization of antinutritional factors containing fodders or feed is not a healthy approach. Likewise, many other *Acacia* species like *A. giraffae*, *A. cunninghamii*, *A. sieberiana*, and *A. berlandieri* have been reported as sources of antinutritional factors. Not only *Acacia* species but many other fodder trees like *Azadirachta india*, *Albizia stipulate*, *Sesbania sesban*, and *Sesbania vesicaria* are also sources of antinutritional factors (Kumar 1992). All of these trees are being utilized as livestock fodder, but their utilization may cause toxic effects in livestock animals. These problems are mainly faced in those regions where trees and natural pastures are preferred by local farmers to feed their livestock animals, like African countries (Osuji et al. 1995). The toxicity of antinutritional factors is being overcome by substituting feedstuff with oilseed cakes and animal proteins (Kass et al. 1992).

Moringa leaves are unique because of their tremendous amounts of minerals but lower amounts of harmful compounds. In moringa, tannins and phytates are 12 and 21 g kg^{-1} of DM, respectively, while 65% supplementation of *Leucaena leucocephala* leaves in the normal diet of ruminants may give rise to tannins and phytates up to 29.40 and 1.43 mg 100 g^{-1} of dry matter, respectively (Udom and Idiong 2011). Some other fodder tree leaves like those of *Sesbania sesban*, *Acacia angustissima*, and *Acacia cyanophylla* contain 31, 66, and 38 g kg^{-1} tannin contents, respectively (Ahn et al. 1989; Kaitho 1997; Salem et al. 1999). Aside from this, moringa leaves lack lectins, trypsin, and amylase inhibitors (Ferreira et al. 2008), but possess sugar-modified glucosinolates (dominated by glucomoringin in leaves and glucotropaeolin in roots) (Fahey et al. 2001; Bennett et al. 2003; Newton et al. 2010), although their concentration varies widely depending upon the soil time, climate, growth stage, and cultivar/species (Farnham et al. 2000, 2004). Cartea et al. (2007) and Charron et al. (2005) reported higher concentrations of glucosinolates on long and warmer days. A few derivatives of glucosinolates, like thiocarbamates, isothiocyanates (pungent and spicy), and carbamates by the action of myrosinase have also been reported in moringa leaves (Leuck and Kunz 1998), but their concentration is very low as compared with other phytochemicals and somehow cannot be found in moringa tissues (Newton et al. 2010). Moreover, Doerr et al. (2009) suggested that moringa plants can be grown for their health benefits with a mild taste and good health benefits of glucosinolate compounds. These derived compounds are being reported as responsible agents for the bitter or pungent taste of moringa leaves (Doerr et al. 2009). Raw soybean leaves contain a trypsin inhibitor that affects young animals. The antinutritional effect of soybean meals can be eliminated by a heating process, but this causes deterioration of the nutritional value of soybean leaves, especially reduction in amino acid components and CP (Mikic et al. 2009). Although moringa leaves have saponins, which gives a

Table 6. Mineral contents in moringa pods.

Nutritional contents	Moringa pods (mg kg^{-1})	References
Calcium	1248	Fuglie 2000; Newton et al. 2010
Phosphorous	1757	Fuglie 2000
Magnesium	133.45	Aykroyd 1966; Fuglie 2000; Newton et al. 2010
Sodium	1709	Foidl et al. 2001; Newton et al. 2010
Potassium	15,416.5	Makkar and Becker 1996, 1997; Newton et al. 2010
Iron	231.2	Makkar and Becker 1996, 1997
Manganese	57.73	Fuglie 1999, 2000; Foidl et al. 2001
Zinc	21.9	Foidl et al. 2001; Newton et al. 2010
Copper	27.67	Aykroyd 1966; Fuglie 2000
Sulfur	1147	Aykroyd 1966; Fuglie 2000

bitter taste to livestock while eating, these do not always have harmful effects on animals or human beings (Makkar and Becker 1996, 1997). The extracts of moringa leaves contain amounts of saponins ranging between 4.7 and 5 g kg^{-1} of DM, and so they can be consumed by livestock and human beings without any adverse effects (Liener 1994; Makkar and Becker 1997; Price 2000; Foidl et al. 2001). This research area of moringa (bioactive compounds and phytochemicals) needs more attention from scientists to find out the catabolism and absorption of these compounds being consumed in order to have a complete view on moringa's effects on health.

Other potentially harmful compounds commonly found in several fodder plants are soluble oxalates, and especially calcium oxalates. These molecules can cause digestive problems and the formation of kidney stones not only in animals but also in human beings (Finkielstein and Goldfarb, 2006). *Acacia aneura* has also been reported as containing oxalates in its leaves, which is not preferred for livestock fodder. In contrast to some other leafy vegetables (*Amaranthus polygonoides* and *Amaranthus tricolor*) that have high levels of calcium soluble oxalates, moringa leaves have higher contents of available calcium and insoluble oxalates, which are not harmful for human beings or animals (Noonan and Savage 1999; Radek and Savage 2008). The oxalates present in *Acacia* species reduce the calcium digestion in livestock. Moringa leaves are rich in calcium contents (18,747.14 mg kg^{-1} on DM basis), although they might become a source of soluble oxalates, which can be responsible for kidney stone formation. Moringa leaves contain 2754 mg kg^{-1} total oxalates (Table 7), which all are insoluble, while spinach leaves, which are also rich in iron and calcium, contain 125,762 mg kg^{-1} total oxalates, among which 118,998 mg kg^{-1} are soluble (Radek and Savage 2008). These soluble oxalates can further cause kidney stone formation. These findings reveal that moringa

Table 7. Soluble and insoluble oxalates quantity in different leafy vegetable in comparison with moringa leaves (Noonan and Savage 1999; Radek and Savage 2008).

Vegetable/plants	Total oxalates (mg kg^{-1})	Soluble oxalates (mg kg^{-1})	Insoluble oxalates (mg kg^{-1})
Spinach	125,762	118,998	6763
Green amaranths	100,563	46,747	53,817
Purple amaranths	81,060	35,580	45,480
Curry	27,749	-	27,749
Moringa	27,540	-	27,540
Onion	5328	-	5328
Coriander	5132	-	5132
Radish	2090	-	2090

leaves can be eaten as a richer calcium source, especially by mothers and children, without the fear of kidney stone formation.

Moringa seeds have the highest amount of phytates and glucosinolates compared to other vegetative parts (Oliveira et al. 1999; Foidl et al. 2001; Ferreira 2004). The presence of alkaloids and saponins (in safe ranges, as described earlier) and the negligible amount of tannins is responsible for the bitter taste of the seeds, but such unpleasant taste can be eliminated using certain treatments like boiling or extraction processes, gene manipulation, and supplementation with methionine or threonine (Enneking and Wick 2000).

Antivitamin agents (which make a vitamin ineffective or lower its chemical action inside the body) for vitamins A, D, E and K and pyridoxine have been found in many conventional fodders and feeds like soybean, sweet clover, *Phaseolus vulgaris*, and linseed cake (Nityanand 1997). These antivitamin agents cannot be completely eliminated from these livestock feedstuffs (Akinmutimi 2004). The presence of these toxic elements in livestock feed may cause kidney and liver damage due to abnormalities caused by rapid metabolic rates to inhibit the effects of these antivitamin agents (Bone 1979). However, moringa leaves are a rich source of vitamins (Makkar and Becker 1997; Nambiar and Seshadri 1998; Nambiar and Seshadri 2001). There is no study available on the presence of antivitamin agents or activities in moringa leaves, but it has been found that moringa leaves and moringa leaf meal are good feed sources for livestock, fish, rabbits, laying hens, broiler chickens, growing sheep, and cross-bred cows (Afuang et al. 2003; Sarwatt et al. 2004; Dongmeza et al. 2006; Kakengi et al. 2007; Nuhu 2010; Olugbemi et al. 2010).

Aside from the negligible antinutritional factors, moringa leaves are palatable for human beings and livestock. These studies manifest the fact that moringa has better nutritional quality than other leafy vegetables or fodders.

6. Summary

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. One of its main virtues is its surprising versatility, because it can be grown as crop or tree fences in alley cropping systems, in agroforestry systems, and even on marginal lands with high temperatures and low water availabilities where it is difficult to cultivate other agricultural crops. Aside from that, it does not deplete the existing resources or change land use patterns.

7. Future directions

This review article summarizes the information available on moringa strengths and potential advantages. The usage and virtues of this species, like as livestock fodder, have been widely documented, but many aspects of this plant, from the most convenient agricultural practices to its beneficial or harmful effects for livestock, are still waiting for further research.

In the case of agricultural practices, for instance, there is not a consensus about the proper sowing densities and harvesting frequencies. Different scientists have reported varying planting densities and cutting frequencies for getting maximum biomass with good nutritional quality, but the response of individual plants has not yet been studied. Studies that allow establishment of the optimum cutting height for moringa plants are still missing, as is research that quantifies the improvement in the quality of milk and meat triggered by the use of moringa as fodder (although it has been proven that the use of moringa increases milk yield). Aside from this, its fertilizer and irrigation requirements as a fodder crop have not yet been studied, which needs attention for more biomass production. Policy makers and research and extension institutions should formulate programs focusing on generating awareness among local communities and farmers, especially among those who are engaged in livestock production, to emphasize the planting of moringa as a crop for their livestock.

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