Research Advances in the Application of Moringa in Animal Feed: Postprint

Authors: Wang Peng, Chen Ting, Sun Jiajie, Xi Qianyun, Zhang Yongliang

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Abstract

Moringa is a tropical deciduous tree with special economic value, characterized by high yield, wide adaptability, simple cultivation, and strong stress resistance. Moreover, Moringa possesses high nutritional value, with crude protein content reaching up to 27% in leaf dry matter, a well-balanced amino acid composition, and abundant vitamins, mineral elements, and unsaturated fatty acids, making it a rare and valuable feed resource. Therefore, this paper introduces the biological characteristics and nutritional levels of Moringa, reviews its effects as a feed resource on animal growth and development and product quality, as well as its health-promoting functions in animal farming, aiming to provide a reference for the promotion and application of Moringa as a novel feed resource.

Full Text

Research Progress in the Application of *Moringa oleifera* in Animal Feed

WANG Peng, CHEN Ting, SUN Jiajie, XI Qianyun, ZHANG Yongliang*

(Guangdong Provincial Key Laboratory of Animal Nutrition Control, National Engineering Research Center for Swine Breeding Industry, College of Animal Science, South China Agricultural University, Guangzhou 510642, China)

Abstract: *Moringa oleifera* is a tropical deciduous tree with exceptional economic value, characterized by high yield, broad adaptability, simple cultivation, and strong stress resistance. The plant exhibits high nutritional value, with crude protein content reaching up to 27% in leaf dry matter, balanced amino acid composition, and abundant vitamins, mineral elements, and unsaturated fatty acids, making it a valuable feed resource. This review introduces the biological characteristics and nutritional profile of *M. oleifera*, examines its effects on animal growth, development, and product quality as a feed resource, and discusses its health-promoting functions in animal production, providing a reference for the promotion and application of *M. oleifera* as a novel feed resource.

Key words: *Moringa oleifera* feed; feed resource; animal health care; healthy breeding

With continuous improvement in living standards, Chinese consumers' demand for meat products has increased substantially, accompanied by growing concerns about meat quality and safety. This has necessitated the accelerated development of green and efficient animal husbandry practices. However, increasing population pressure, energy crises, and decreasing arable land have intensified competition between humans and livestock for grain resources, severely constraining the development of the animal production sector. *Moringa oleifera* offers a promising solution as a feed source that does not compete with food crops for land. Internationally acclaimed as the "miracle tree" and "plant diamond," it is characterized by rich nutritional content, broad adaptability, strong stress resistance, easy cultivation, high yield, and short harvest cycles, demonstrating excellent potential as an animal feed resource.

Native to northwestern India and northeastern Africa, *M. oleifera* is widely cultivated in Cuba, Africa, and Southeast Asia, with additional plantings in the Arabian Peninsula, Pacific region, Caribbean islands, and South America. Asia currently has the largest cultivation area, followed by the Americas and Africa. In China, the total cultivation area has exceeded 10,000 hectares, distributed across Guangdong, Fujian, Guangxi, Yunnan, Taiwan, and Hainan provinces, with Yunnan accounting for the largest share at approximately 6,700 hectares (over 60% of the national total) [1]. In economically developed regions such as Guangdong and Fujian, large-scale and industrialized *M. oleifera* cultivation bases have been established through the promotion of enterprises and research institutions.

1. Biological Characteristics of *Moringa oleifera*

Moringa oleifera, also known as the drumstick tree, belongs to the order Capparales and family Moringaceae. This arboreal species features soft woody bark, branches with distinct lenticels and leaf scars, and twigs covered with short pubescence. Currently, 14 varieties are known. The plant exhibits strong vitality and low environmental requirements, capable of rapid growth even in poor soils or harsh climatic conditions. It can thrive in slightly acidic to slightly alkaline soils and adapt to various soil types including sandy and clay soils. *M. oleifera* demonstrates remarkable resilience, surviving in both humid and arid environments, tolerating temperatures up to 48°C under shade, and withstanding light frost. Propagation can be achieved through seeds or cuttings from lignified branches. These exceptional characteristics have earned it the title "tree of immortality."

2. Nutritional Value of *Moringa oleifera*

The leaves, pods, and seeds of *M. oleifera* are characterized by high protein and low fiber content [2]. In leaf meal dry matter, crude protein content exceeds 25%, with true protein reaching up to 81.3% [3]. The leaves contain 14-17 fatty acids, with linolenic acid accounting for 57% of total fatty acids (Table 1) [4]. In the seeds, crude protein and *Moringa* oil content are 37% and 34%, respectively [5], with unsaturated fatty acids comprising over 80% of the seed oil and oleic acid content reaching 70%. The fatty acid profile is comparable to that of olive oil [6].

Moringa contains diverse and abundant amino acids, with 17 types identified in the leaves. Glutamic acid is the most abundant, representing 14.52% of total amino acids, while lysine and threonine are also present at high levels (Table 1) [7], making it an excellent protein source. The leaves are rich in vitamins, particularly carotenoids, B-complex vitamins, vitamin C, vitamin E, folic acid, pantothenic acid, and biotin (Table 1) [8]. Mineral content includes six macroelements (calcium, magnesium, phosphorus, potassium, sodium, sulfur) and five trace elements (zinc, copper, iron, manganese, selenium) (Table 1) [9], enabling the use of *M. oleifera* leaf meal as an iron supplement for improving animal performance [10].

The primary bioactive compounds in *M. oleifera* are flavonoids, polysaccharides, and polyphenols. Isothiocyanates, a type of polyphenol, are particularly abundant and possess strong antioxidant capacity [13]. Additionally, the leaves contain compounds such as kaempferol, *Moringa* alkaloids, zeatin, *Moringa*in, kaempferol, and chlorogenic acid, which exhibit antioxidant, antitumor, and antibacterial properties, establishing *M. oleifera* as a natural multifunctional health product.

As an unconventional feed, *M. oleifera* contains minimal anti-nutritional factors, primarily phenols and saponins. Phenol concentrations are far below toxic thresholds for animals, while saponins are inert and non-toxic. Reported levels include tannins at 20.7 mg/g, trypsin inhibitors at 1.45 TIU/g, nitrates at 17 mg/g, and oxalates at 10.5 mg/g in leaf meal [14]. These data support the promising application prospects of *M. oleifera* in animal feed.

3. Application of *Moringa oleifera* in Animal Diets

3.1 Swine Diets

Research indicates that *M. oleifera* leaf meal can serve as a high-quality protein feed source. Supplementing Mangalarga pigs with leaf meal did not negatively affect growth while maintaining nitrogen balance and improving nitrogen digestibility and utilization [15]. Zhang et al. [16] added 3%, 6%, and 9% leaf meal to crossbred finishing pig diets, finding that the 6% group showed significantly higher final body weight, average daily gain, and carcass length, along with significantly reduced backfat thickness compared to the control. Both 3%

and 6% groups exhibited significantly improved feed-to-gain ratio, while 6% and 9% groups showed enhanced serum and muscle superoxide dismutase activity and total antioxidant capacity. All treatment groups had significantly reduced serum malondialdehyde content, though muscle dry matter, crude protein, and crude fat content remained unchanged.

Mukumbo et al. [17] supplemented growing-finishing pig diets with 2.5%, 5.0%, and 7.5% leaf meal, finding that levels up to 5.0% did not adversely affect growth performance, feed conversion, or meat quality, while extending pork shelf life. At 7.5% inclusion, daily feed intake increased significantly but feed conversion efficiency decreased. Conversely, Ruckli et al. [18] reported negative effects, where replacing 7.18% soybean meal with 15.56% leaf meal significantly reduced average daily feed intake, daily gain, and carcass weight, though it decreased subcutaneous fat and increased lean meat percentage. While leaf meal showed disadvantages as a protein source compared to soybean meal, it produced healthier meat quality aligned with modern dietary preferences. The bitter taste of leaf meal may reduce feed palatability at high inclusion rates, suggesting that sweeteners could be added to improve acceptability. Collectively, these studies indicate that moderate leaf meal supplementation (optimal at 6%) in finishing pig diets improves nitrogen utilization, growth performance, antioxidant function, and meat quality, though excessive levels reduce feed intake. Additionally, Pfaff [19] reported that aqueous leaf extract fed to weaned piglets did not negatively affect growth and showed a trend toward increased daily gain.

3.2 Rabbit Diets

Dougnon [20] added leaf meal at 0% (control), 10%, and 15% to rabbit diets, observing significantly improved daily gain, feed conversion, and crude protein utilization in supplemented groups, with the 15% group showing marked improvements in growth performance and carcass quality. Safwat et al. [21] found that leaf meal inclusion up to 40% did not negatively affect growth performance or carcass quality while improving economic returns. Nuhu [22] replaced soybean meal with leaf meal at 0%, 5%, 10%, 15%, and 20% in mixed diets for young rabbits, with all treatment groups showing significantly higher daily gain than the control, and an upward trend with increasing inclusion levels. Sun et al. [23] substituted alfalfa meal with 0%, 10%, 20%, and 30% leaf meal, finding that the 20% group had significantly higher daily gain and feed conversion than the control. Leaf meal supplementation significantly improved growth performance, meat quality, and blood biochemical parameters. These results demonstrate that *M. oleifera* leaf meal enhances rabbit growth performance, carcass quality, antioxidant function, and blood indices.

3.3 Dairy Cattle Diets

Moringa oleifera is primarily used as fresh or ensiled forage in dairy cattle diets. When fresh or ensiled leaves served as the main roughage compared to elephant grass, ensiled leaves improved protein and fiber digestibility without significantly affecting milk yield or composition. Fresh *Moringa* imparted a pleasant fresh-grass flavor and aroma to milk without altering color or appearance [24]. Cohen-Zinder et al. [25] fed cows an ensiled mixture of *M. oleifera*, wheat hay, and molasses, increasing milk yield by 1.91% and 4% fat-corrected milk by 4.26% while enhancing milk antioxidant capacity. Ensiled *Moringa* can replace partially alfalfa hay and corn silage without negatively affecting milk production, nutrient digestibility, or serum biochemical indices [26]. Mendieta et al. [27] replaced soybean meal with leaf meal, finding no significant differences in digestion and absorption indicators except for reduced crude protein digestibility, without affecting milk composition. Zhang Xingyi et al. [28] replaced 50% of dietary alfalfa with *Moringa* stems and leaves, observing increased dry matter intake and milk yield trends, significantly improved milk protein percentage, protein yield, and total solids, along with enhanced plasma total antioxidant capacity, hydroxyl radical scavenging ability, and immunoglobulin content, and reduced plasma malondialdehyde, cholesterol, and triglycerides. These findings indicate that moderate *Moringa* supplementation improves milk yield and quality, antioxidant status, and immune function in dairy cows, establishing its value as a quality roughage.

3.4 Goat Diets

Kholif et al. [29] replaced over 50% of sesame meal with leaf meal in goat diets, finding increased feed intake, improved digestive function, significantly enhanced milk yield and quality, and increased unsaturated fatty acids and conjugated linoleic acid in meat, improving meat quality and confirming leaf meal as a viable protein feed resource. Kholif et al. [30] compared ensiled, fresh, and hay forms of leaf meal as sesame meal replacements, with ensiled leaves showing superior results. Moyo et al. [31-32] fed leaf meal to crossbred Xhosa lop-eared goats, significantly improving growth performance and carcass quality, producing redder meat with improved taste and flavor after cooking. Sultana et al. [33] fed goats varying ratios of leaf meal and elephant grass, finding positive linear relationships between leaf meal proportion and crude protein digestibility, with significantly improved nitrogen retention. These studies demonstrate that leaf meal supplementation enhances crude protein utilization, growth performance, milk yield and quality, and carcass characteristics in goats.

3.5 Poultry Diets

Moringa oleifera' s rich nutrient profile makes it suitable for broilers and layers. Studies report that leaf meal inclusion up to 15% does not adversely affect blood or serum biochemical indices [34]. Kumar et al. [35] added 0%, 5%, 10%, 15%, and 20% leaf meal to broiler diets, finding significantly reduced serum total cholesterol and triglycerides and increased fatty acid content, with 5% inclusion optimizing both economic returns and meat quality. Leaf extract supplementation improved meat quality and antioxidant capacity in Cobb broilers [36].

Other studies show that 20% leaf meal inclusion significantly improved blood lipid profiles and hematological indices [37], and enhanced hematological and biochemical parameters while improving heat stress resistance [38]. William et al. [39] observed significantly increased plasma total protein with increasing leaf meal levels, likely due to antioxidant compounds regulating corticosterone secretion to limit protein catabolism. Khan et al. [40] added 0%, 0.6%, 0.9%, 1.2%, and 1.5% leaf meal to corn-based diets, finding no significant effects on feed intake, conversion, bursa weight, or intraepithelial lymphocyte count. However, at 1.2% inclusion, body weight, intestinal length and weight, villus height in duodenum, jejunum, and ileum, ileal crypt depth, duodenal goblet cell count, and intestinal acidic mucin and bursal counts were significantly higher than the control, establishing 1.2% as the optimal inclusion level. Teteh et al. [41] reported significant intestinal elongation in Isa Brown hens fed 1% and 2% leaf meal for 56 days. Additionally, leaf meal improves product coloration, enhancing comb, beak, and shank pigmentation in broilers [42]. These findings demonstrate that leaf meal improves intestinal structure, digestive capacity, meat quality, antioxidant capacity, and blood indices, maintaining birds in healthy condition.

Moringa oleifera also improves egg quality. Leaf meal supplementation does not adversely affect laying performance, egg quality, yolk nutrient content, or serum biochemical indices, while significantly increasing yolk color and reducing serum total cholesterol and low-density lipoprotein cholesterol [43]. Lu et al. [44] fed Hy-Line Gray layers corn-soybean diets with 0%, 5%, 10%, and 15% leaf meal, finding no significant differences in feed intake or egg weight, but significantly improved feed conversion at 15% inclusion and deeper yolk color at 5% inclusion. The recommended optimal level is 5%, which improves yolk color and protein absorption without affecting laying performance or egg quality. Increasing leaf meal levels significantly increased albumen proportion [45], with 2.5% and 5.0% inclusion significantly improving albumen height [46-47]. Therefore, *M. oleifera* supplementation does not negatively affect laying performance or egg quality but improves yolk color and albumen proportion, allowing adjustment of albumen-to-yolk ratios to meet consumer preferences.

Limited research exists on waterfowl. In Qingyuan geese, stem meal was added at 0%, 2%, 4%, 6%, 8%, and 10%, revealing increased feed-to-gain ratio with higher inclusion levels, with significant elevation at 8% compared to the control. Stem meal at certain levels increased muscle and fat proportions, enabling production of leaner geese according to consumer demands. At 6% inclusion, serum total protein, albumin, low-density lipoprotein, and lactate dehydrogenase activity were significantly lower, possibly due to bioactive compounds reducing serum protein content. Stem meal did not adversely affect organ or intestinal development or breast meat color and pH. Therefore, stem meal inclusion in goose diets should not exceed 6%, with attention to protein supplementation [48].

3.6 Aquaculture Feeds

Studies have investigated leaf meal effects on tilapia growth and feed utilization. Replacing 8.7% wheat middlings and 6.3% rapeseed meal with 15% leaf meal significantly increased final body weight and weight gain while reducing feed coefficient, though survival rate was slightly lower [49]. In red-fin silver barb, 2% and 6% leaf meal supplementation significantly increased average body weight and muscle cell growth rate after 28 days, with new muscle fiber formation, demonstrating no negative health effects while improving growth performance [50]. Astuti et al. [51] compared ethanol-extracted leaf meal with mulberry leaf meal, finding both could replace 30% fish meal in Nile tilapia diets, with *Moringa* showing superior results. However, anti-nutritional factors including polyphenols, tannins, saponins, and phytic acid may affect fish growth and health when leaf meal exceeds 25% inclusion [52]. These results indicate that moderate leaf meal supplementation improves fish growth performance and reduces feed coefficient, while excessive levels may negatively impact fish health.

4. Conclusion and Prospects

Feed plant resources are fundamental to animal production development. In recent years, the contradiction between feed shortage and rapid industry growth has become increasingly prominent in China, with conventional feeds unable to meet market demand and severely constraining industry development. Developing woody feed resources as novel feed sources is strategically important for transforming China from a large animal production country to a strong one and for ensuring national food security. *Moringa oleifera* is nutritionally rich, easy to cultivate, highly productive, and fast-growing, offering tremendous development potential as an animal feed.

Domestic and international research has confirmed that moderate *M. oleifera* supplementation improves animal growth performance and enhances meat, egg, and milk production and quality. However, challenges remain in transitioning from woody plant to feed product. As a tropical and subtropical plant currently cultivated only in small areas in southern China, further introduction trials are needed to test ecological adaptability across different regions and expand cultivation area. Harvesting and feed processing technologies remain underdeveloped, and experimental data across different animal species are insufficient, requiring more animal trials for reference. Therefore, industrialization of *M. oleifera* feed remains a formidable task requiring greater research and promotion efforts to open new avenues for China’ s feed resources.

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