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Abstract

Moringa is native to the southern foothills of the Himalayas in northern India and represents the most extensively utilized and researched species within the Moringa genus, possessing the highest commercial value. Numerous studies have demonstrated that various parts of Moringa, including roots, bark, leaves, and seeds, contain bioactive compounds such as flavonoids, polysaccharides, alkaloids, and phenolic compounds. Additionally, Moringa exhibits antibacterial, anti-inflammatory, and intestinal development-promoting effects, demonstrating potential utility in maintaining animal health and preventing disease. Therefore, this review summarizes the nutritional value, chemical composition, pharmacological properties of Moringa, as well as its applications in antibacterial, anti-inflammatory, and livestock production contexts, aiming to provide a theoretical foundation for the development of Moringa extracts as natural functional feed additives.

Full Text

Antibacterial and Anti-inflammatory Effects of Moringa and Its Application in Animal Production

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Abstract: Moringa oleifera, native to the southern foothills of the Himalayas in northern India, is the most utilized, researched, and commercially valuable species within the Moringa genus. Extensive research has shown that multiple parts of Moringa oleifera—including roots, bark, leaves, and seeds—contain

bioactive substances such as flavonoids, polysaccharides, alkaloids, and phenolic compounds. Furthermore, Moringa exhibits antibacterial, anti-inflammatory, and intestinal development-promoting effects, demonstrating potential value in maintaining animal health and preventing disease. This review summarizes the nutritional value, chemical composition, pharmacological properties, and applications of Moringa in antibacterial and anti-inflammatory contexts, as well as its use in livestock production, aiming to provide a theoretical foundation for developing Moringa extracts as natural functional feed additives.

Keywords: Moringa oleifera; antibacterial; anti-inflammatory; intestinal development; intestinal health

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Moringa oleifera Lam., also known as the drumstick tree, is a perennial tropical deciduous tree with approximately 14 varieties worldwide, and it is now widely cultivated in China. Reports indicate that Moringa can be applied in water purification, development of novel pharmaceuticals, and as a raw material for daily cosmetics [1]. Additionally, in the ancient Indian healthcare system of Ayurveda, Moringa leaves were documented for treating various diseases. Modern medicine has screened plants based on their traditional uses and nutritional value, finding Moringa to be a safe and medicinally valuable plant. Due to its advantages of high calcium, high protein, high fiber, and low lipid content [2], along with hypoglycemic, hypolipidemic, antioxidant, and antitumor effects [3], Moringa has attracted considerable attention as a novel health-promoting plant (food) in recent years. Concurrently, its antibacterial and anti-inflammatory activities have garnered extensive academic research. This paper primarily summarizes domestic and international studies on the antibacterial and anti-inflammatory effects of different Moringa parts, as well as its roles in improving animal production performance, slaughter performance, antioxidant capacity, and immune regulation, providing support for enriching the biological functions of Moringa.

1. Chemical Composition of Moringa

Plants produce primary and secondary metabolites, including alkaloids, phenolic compounds, tannins, phytosterols, and terpenoids, which play active roles in various biological processes. However, among the more than 750,000 plant species on Earth, only 1% to 10% have been potentially utilized, and Moringa belongs to this category [4]. In recent years, domestic and international research has focused on the extraction, isolation, identification, and bioactivity analysis of Moringa's functional components, with Moringa flavonoids, polyphenols, polysaccharides, glycosides, and Moringa proteins being current research hotspots [5]. For instance, Zhang et al. [6] optimized extraction conditions for total flavonoids from Moringa, achieving a content of 3.139%; Wang [7] identified that flavonoids in Moringa leaves are primarily quercetin and kaempferol and their derivatives, mostly flavonoid glycosides. Additionally, researchers have

extracted steroids, alkaloids, and other active substances from Moringa, among which benzyl isothiocyanate and phenyl isothiocyanate have been reported to possess certain antibacterial and anti-inflammatory effects [8-9]. Therefore, the main functional chemical components of Moringa include flavonoids, alkaloids, polysaccharides, etc. The chemical composition of various Moringa parts is shown in Table 1 .

2. Nutritional Value of Moringa

Moringa is rich in protein and amino acids, and also contains high levels of vitamin A and vitamin C [17], making it an ideal food for vegetarians and a high-quality protein source for animal feed. Research shows that Moringa leaves contain 10 times more vitamin A than carrots, 17 times more calcium than milk, 15 times more potassium than bananas, 25 times more iron than spinach, 9 times more protein than yogurt, and higher vitamin C content than oranges [18]. Xu et al. [19] reported that Moringa leaves are rich in protein (approximately 6% in fresh leaves and 27% in dried leaves), with amino acid composition dominated by aspartic acid and glutamic acid, and containing essential amino acids including threonine, valine, isoleucine, lysine, phenylalanine, and methionine. Yameogo et al. [20] analyzed the mineral composition of fresh Moringa, finding calcium, magnesium, potassium, iron, zinc, and phosphorus contents of 8,471, 1,513, 5,496, 175, and 1,115 mg/kg, respectively. Guo et al. [21] found that different parts of Moringa oleifera have varying nutrient profiles: leaves contain the highest levels of protein, vitamin E, vitamin C, niacin, vitamin B6, -carotene, magnesium, calcium, and phosphorus; stems contain the highest levels of dietary fiber, copper, zinc, and manganese; fruits contain the highest levels of folate, potassium, and sodium; while roots contain the highest levels of carbohydrates and iron. Thus, Moringa is a plant with high nutritional value, rich in protein, vitamins, and mineral elements.

3. Pharmacological Activity of Moringa

Reports on the medicinal activities of Moringa are extensive. Various parts such as leaves, roots, seeds, bark, fruits, flowers, and immature pods can act as cardiac and circulatory stimulants, exhibiting antitumor, antipyretic, antiepileptic, anti-inflammatory, anti-ulcer, antispasmodic, diuretic, hypotensive, lipid-lowering, antioxidant, antidiabetic, and antibacterial effects. These properties have been used to treat different diseases in indigenous medical systems, particularly in South Asia [22]. This article excerpts some reported medicinal values of Moringa. The pharmacological effects of various Moringa parts are shown in Table 2 .

4. Antibacterial Effects of Moringa

As summarized from Moringa' s pharmacological activities, it possesses functions including antibacterial and anti-inflammatory effects, immune regulation, disease resistance, hypoglycemia, and hypolipidemia. Currently, reports on

Moringa' s antibacterial efficacy have primarily focused on two parts: leaves and seeds.

Lalas et al. [40] used Moringa seed oil extract to demonstrate inhibitory effects against *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Enterobacter cloacae*, *Klebsiella pneumoniae*, *Candida albicans*, *Candida tropicalis*, and *Candida glabrata*. Similarly, Jabeen et al. [41] found that crude extracts, supernatants, residues, and dialyzed samples from Moringa seeds could inhibit the growth of various bacteria and fungi, with *Pasteurella multocida* and *Bacillus subtilis* being the most sensitive. The study also showed that the extract' s activity was interfered with by cations such as sodium (Na⁺), potassium (K⁺), magnesium (Mg²⁺), and calcium (Ca²⁺), with highest activity at temperatures of 4–37°C and pH 7. Bukar et al. [42] found that Moringa seed chloroform extract at a concentration of 1 mg/mL could 100% inhibit the growth of *Mucor* and *Rhizopus*, with antibacterial effects equivalent to the standard drug ketoconazole at 0.5 mg/mL. Researchers have also investigated antibacterial active substances in Moringa seeds. Singh et al. [14] isolated and purified phenolic compounds from defatted Moringa seed powder, finding that bound phenolic extracts (minimum inhibitory concentration [MIC] 0.06%–0.157%) exhibited greater antibacterial activity than free phenolic extracts (MIC 0.117%–0.191%). Padla et al. [39] demonstrated that benzyl isothiocyanate from Moringa seeds showed inhibitory effects against Gram-positive bacteria and dermatophytic fungi such as *Trichophyton mentagrophytes* and *Trichophyton rubrum* at an MIC of 1 mg/mL.

Jeon et al. [9] isolated niazimicin and 4-(L-rhamnosyloxy)-benzyl isothiocyanate (RBI) from Moringa seeds, finding that RBI possessed stronger antibacterial activity than niazimicin, and suggesting that the difference in their antibacterial activity might be related to ethyl groups.

Regarding Moringa leaves, Bukar et al. [42] found that ethanol extracts of Moringa leaves exhibited broad-spectrum antibacterial effects against *E. coli*, *P. aeruginosa*, *S. aureus*, and *Enterobacter aerogenes*, with MIC values for various microorganisms ranging from 2.0–4.0 mg/mL. Jayawardana et al. [43] added Moringa leaves to chicken sausages and found significant inhibitory effects against *E. coli* and *S. aureus* without any adverse effects on sausage sensory properties. Pal et al. [44] showed that ethanol extracts of Moringa leaves could significantly inhibit the growth of Gram-positive bacilli, *B. subtilis*, *Staphylococcus*, *Bacillus alvei*, Gram-negative bacilli, and acid-fast *Mycobacterium*. Meanwhile, Marrufo et al. [45] found that medium and high doses (5, 10 g) of Moringa leaf essential oil exhibited inhibitory effects against bacteria such as *Bacillus cereus* and *P. aeruginosa*, as well as fungi including *Penicillium aurantiogriseum*, *Penicillium expansum*, *Penicillium citrinum*, *Penicillium digitatum*, and *Aspergillus niger*.

In addition, limited reports have addressed the antibacterial effects of other Moringa parts. Arora et al. [46] demonstrated that flavonoids and diterpenoids from Moringa pod husks could combat various important pathogenic bacteria,

including methicillin-resistant *Staphylococcus aureus* (MRSA).

Research indicates that the content of active components in Moringa may be influenced by variety, region, season, and other factors. Ndhala et al. [47] showed that phytochemical levels and antibacterial activity varied among 13 Moringa cultivars, though no direct correlation existed between biological activity and levels of total phenolics or flavonoids. Ratshilivha et al. [48] investigated differences in antibacterial activity of acetone extracts from South African Moringa samples collected in different months, finding that Moringa pods exhibited strong inhibitory effects against *P. aeruginosa*, *S. aureus*, *E. coli*, and *Enterococcus faecalis* during specific winter months. Additionally, Zhang [49] reported similar results, showing that Moringa's chemical components such as flavonoids, polysaccharides, alkaloids, and water-soluble proteins vary with harvest time, plant part, and cultivar.

Based on the above reports, Moringa leaves, seeds, and pod husks contain antibacterial active substances with certain effects against both bacteria and fungi. However, relatively few reports exist on the antibacterial activity or other medicinal activities of other parts such as Moringa roots, flowers, and bark, warranting further research exploration.

5. Anti-inflammatory Effects of Moringa

In addition to antibacterial effects, Moringa extracts also possess anti-inflammatory properties. Minaiyan et al. [37] found that a certain dose of Moringa seed hydroalcoholic extract effectively reduced the weight of the distal 8 cm of the colon in mice (a marker of inflammation and tissue edema), suggesting that biophenols and flavonoids may be the main components for treating experimental colitis. Araújo et al. [50] confirmed both in vitro and in vivo anti-inflammatory effects of Moringa seed extract in acute inflammation models established by lipopolysaccharide (LPS)-stimulated macrophages and mice, further determining that it may achieve anti-inflammatory effects by modulating cytokine and nitric oxide (NO) synthesis. Similarly, Cheenpracha et al. [8] found that compounds isolated and purified from ethyl acetate extracts of Moringa fruits exhibited anti-inflammatory activity against LPS-induced mouse macrophages. Further analysis revealed that 4-[20-acetyla-L-rhamnosyloxy]benzyl isothiocyanate in the extract strongly inhibited nitric oxide with a half-maximal inhibitory concentration (IC₅₀) of 1.67 mol/L.

Anti-inflammatory activity of other Moringa parts besides seeds and fruits has also been reported. Sashidhara et al. [51] isolated acetate and 1,3-dibenzylurea compounds from Moringa roots that significantly inhibited inflammatory cytokine production. Kooltheat et al. [52] demonstrated in an in vitro model that Moringa leaf water-methanol extract inhibited cytokine production [tumor necrosis factor (TNF), interleukin-6 (IL-6), and interleukin-8 (IL-8)] in human macrophages. Data showed that the extract could inhibit the expression of RelA, a key gene in the nuclear factor κ B (NF- κ B) signaling pathway of

inflammatory responses. Additionally, Waterman et al. [53] isolated two isothiocyanates from Moringa leaves that significantly reduced gene expression and inflammatory marker production in promonocytes. Extracts at doses of 1 and 5 mol/L attenuated inducible nitric oxide synthase (iNOS) and interleukin-1 (IL-1) expression, respectively, and reduced nitric oxide and TNF- production.

From the above reports, Moringa exhibits significant anti-inflammatory effects. However, its anti-inflammatory components are complex, and besides the reported biophenols and flavonoids, other components may exist, with mechanisms of action currently not fully understood.

6. Application Effects of Moringa in Animal Production

Due to its high nutritional value, research and development on using Moringa as a feed ingredient or feed additive have emerged in recent years, with related experiments confirming Moringa's potential to promote intestinal development, animal growth, and improve animal product quality. There are numerous reports on Moringa leaves as an unconventional protein feed, while few studies have investigated other parts such as bark, roots, and seeds. Meanwhile, in livestock production, no applications have been reported regarding the use of Moringa as an antibacterial or anti-inflammatory functional feed additive in production animals.

6.1 Effects of Moringa on Animal Production Performance Numerous experiments have demonstrated that Moringa leaves can partially replace animal diets with good feeding effects. Onu et al. [54] fed broiler chicks with 7.5% Moringa leaf powder, showing that final body weight, average daily gain, average daily feed intake, and feed conversion ratio were all significantly better than the control group. However, Zvinorova et al. [55] found that under conditions of insufficient caloric intake for growing animals, using Moringa leaves as a dietary supplement might affect linear growth. Therefore, attention must be paid to dosage and administration when feeding young animals with Moringa. Additionally, in adult animals, Lu et al. [56] found that dietary supplementation with 5% Moringa leaves could improve egg yolk color and protein absorption without adversely affecting laying performance or egg weight. Dietary supplementation with 6% Moringa leaves significantly increased average daily gain and decreased feed-to-gain ratio in finishing pigs [57]. Zhang et al. [58] replaced 50% alfalfa with Moringa stem-leaf diet in dairy cows and found that feed intake and milk production performance during peak lactation significantly improved, while somatic cell count significantly decreased, indicating that Moringa may enhance immune and antioxidant capacity in dairy cows. Thus, the rich nutritional value of Moringa provides substantial potential for developing unconventional feed ingredients, while its green, natural characteristics and broad functional activities offer vast application prospects in developing functional feed additives.

6.2 Effects of Moringa on Animal Fat Metabolism, Antioxidation, and Immune Regulation Numerous experiments have demonstrated that feeding Moringa can improve animal serum indices, particularly those related to lipid reduction and antioxidation. Babiker et al. [59] replaced alfalfa with Moringa in ewe diets and found that the oxidative status of milk and serum improved to a certain extent. Zhang et al. [58] replaced 50% alfalfa in basal diets with Moringa stem-leaf and found that plasma total antioxidant capacity (T-AOC) and hydroxyl radical scavenging ability significantly increased, while serum cholesterol (CHOL) and triglyceride (TG) contents significantly decreased. Meanwhile, Xi et al. [60] found that feeding 8% Moringa leaf powder significantly reduced low-density lipoprotein cholesterol (LDL-C) and total cholesterol (TC) levels in laying hens, improving organism performance. Additionally, Zhang et al. [58] found that Moringa stem-leaf significantly increased immunoglobulin G (IgG) content in dairy cow serum, and IgG has been reported to possess antibacterial and antiviral activities. The aforementioned experiments conducted in production animals further verify that Moringa can improve serum indices and regulate animal immune function to a certain extent.

6.3 Effects of Moringa on Animal Slaughter Performance Animal slaughter performance indicators best reflect the efficacy and value of feed products. Cohen-Zinder et al. [61] used ensiled Moringa as a dietary supplement for meat lambs and found that lambs fed Moringa leaves had longer muscle sarcomeres and lower intramuscular fat content, with no significant differences in collagen content among groups. Li [62] reported that dietary Moringa supplementation at 2%-10% significantly affected the carcass yield of 70-day-old Qingyuan geese, and 10% dietary Moringa significantly increased breast and leg muscle percentages while decreasing abdominal fat percentage. Regarding meat quality improvement, Moyo et al. [63] compared the effects of sunflower seeds and Moringa supplementation in goat diets on the physicochemical characteristics and sensory features of goat meat, finding that Moringa outperformed sunflower seeds in aroma intensity and juiciness, with all sensory indicators significantly better than the control group. Meanwhile, Ayssiwede et al. [64] found that 24% Moringa could deepen the color of broiler carcasses and abdominal fat. Thus, Moringa has economic effects including improving animal slaughter rate, deepening body color, and increasing meat sensory scores, providing a theoretical basis for using Moringa to produce high-end livestock products.

6.4 Effects of Moringa on Animal Intestinal Development Reports indicate that Moringa has a certain promoting effect on animal intestinal development, suggesting that Moringa may facilitate nutrient digestion and absorption, thereby improving animal production efficiency. Khan et al. [65] added Moringa leaf powder at a dose equivalent to 1.2% of broiler body weight to diets and found that the weight and net weight of small intestine and cecum significantly increased, along with significantly increased villus height, surface area, and villus height-to-crypt depth ratio. Meanwhile, Xu [66] investigated the mechanism

of Moringa promoting mouse small intestine growth and found that mice fed 100% Moringa powder diet had small intestine villus length increased by approximately 69.3% compared to the control group, with the surface area for nutrient absorption in the small intestine nearly doubled.

7. Summary

Moringa is rich in nutrients, and the active components contained in its various parts (leaves, seeds, pod husks, etc.) possess broad pharmacological activities, including antibacterial, anti-inflammatory, antioxidant, meat quality improvement, and intestinal development promotion. Therefore, it has significant development potential in animal production, not only alleviating the current shortage of feed resources in China but also enabling the development of Moringa's feed economic value. Although certain achievements have been made in using Moringa as animal feed or feed additives, it remains in the experimental stage. Therefore, before safe and effective Moringa feed products can be introduced to the livestock industry, extensive research is still needed, such as mechanism exploration, effective dose screening, safety evaluation, in vivo metabolism, and residue detection, to ensure efficacy and the safety of livestock and humans.

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