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Moringa oleifera as a Nutraceutical Resource: Nutritional Profile and Its Impact on Broiler Growth Performance

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ABSTRACT

Moringa oleifera Lam (Moringaceae), a highly valued plant native to tropical and subtropical regions, is renowned for its nutritional and medicinal properties, making it a promising resource for both human and animal nutrition. This review aims to comprehensively evaluate the phytochemistry, climatic adaptability, nutritional profile, and effects of M. oleifera as a feed additive in broiler nutrition, with a focus on its potential as a sustainable alternative to antibiotic growth promoters (AGPs) in poultry production. Rich in essential amino acids, vitamins (A, B, C, E), minerals (calcium, potassium, iron), and bioactive compounds such as flavonoids, polyphenols, and antioxidants, M. oleifera exhibits significant medicinal and growth-promoting properties. Numerous studies have explored its incorporation into broiler diets in forms such as M. oleifera leaf meal (MOLM), leaf powder (MOLP), and fermented leaf (FMOL) at inclusion levels ranging from 1–5%. While findings vary, moderate inclusion levels (1–5%) often improve key growth performance parameters, including body weight gain, feed intake, and feed conversion ratio, though higher levels may reduce efficacy due to anti-nutritional factors. This review synthesizes peer-reviewed evidence from 2010–2024 to elucidate M. oleifera's nutritional composition, optimal dietary inclusion, and impact on broiler health and productivity. By highlighting its role as a functional feed additive, this work underscores M. oleifera's potential to support sustainable, health-promoting strategies in broiler production in the post-AGP era.

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INTRODUCTION

Medicinal and aromatic plants have been pivotal in advancing animal nutrition, offering sustainable alternatives to synthetic additives for enhancing health and productivity in livestock (Inoue et al., 2017). Among these, *Moringa oleifera* Lam, a versatile species within the Moringaceae family, has emerged as a highly promising phytogenic feed additive in poultry nutrition due to its exceptional nutritional and bioactive profile (Konmy et al., 2016;

Kuete, 2017). Native to northern India and widely cultivated across tropical and subtropical regions, *M. oleifera* is prized for its leaves, seeds, and pods, which are rich in nutrients and bioactive compounds critical for broiler health and performance (Dalei et al., 2016; Yang et al., 2023). The plant's leaves are particularly notable, containing high-quality proteins, essential amino acids (e.g., lysine, methionine, arginine, leucine), vitamins (A, B-complex, C, E), minerals (calcium, potassium, iron, magnesium), and bioactive compounds such as flavonoids, polyphenols, and antioxidants. These components contribute to its anti-inflammatory, antibacterial, antioxidant, and growth-promoting properties, making it a valuable resource for improving poultry production outcomes (Nkukwana et al., 2014a; Ali et al., 2022).

The global poultry industry is under increasing pressure to replace antibiotic growth promoters (AGPs), banned in regions like the European Union since 2006 due to concerns over antimicrobial resistance, with safe and sustainable alternatives (Nkukwana et al., 2014a). Plant-based feed additives, particularly *M. oleifera*, have gained significant attention for their ability to enhance key physiological processes in broilers, including intestinal morphology, nutrient digestibility, gut microbiota composition, growth performance, and meat quality (Karásková et al., 2015). Research has demonstrated that incorporating *M. oleifera* leaf meal (MOLM), leaf powder (MOLP), or fermented leaf (FMOL) at moderate dietary levels (1–5%) can significantly improve body weight gain, feed intake, and feed conversion ratio, often performing comparably to conventional AGPs (Mousa et al., 2017; Oghenebrorhie & Oghenesuvwe, 2016; Nkukwana et al., 2014b; Khan et al., 2017). These benefits are attributed to *M. oleifera*'s nutrient density and bioactive compounds, which enhance nutrient absorption, reduce oxidative stress, modulate gut microbiota, and support immune function, thereby promoting overall broiler health and productivity (Yang et al., 2023).

The sustainable cultivation of *M. oleifera* in diverse agroecological zones further enhances its appeal as a feed additive, aligning with global efforts to promote environmentally friendly poultry production systems (Gandji et al., 2018). However, variability in study outcomes highlights the need to optimize inclusion levels and processing methods to maximize efficacy while mitigating potential anti-nutritional factors, such as tannins, phytates, and saponins, which may impair nutrient absorption at higher doses (Cui et al., 2018).

This review aims to achieve the following objectives:

1. Evaluate the nutritional and bioactive composition of *M. oleifera* relevant to broiler nutrition;
2. Assess its climatic adaptability and cultivation potential for sustainable feed production;
3. Synthesize evidence on the effects of *M. oleifera* (MOLM, MOLP, FMOL) on broiler growth performance parameters, including feed intake, body weight gain, feed conversion ratio, and final body weight; and

4. Identify optimal inclusion levels and processing methods to enhance its efficacy as a phytogenic feed additive in the post-AGP era, contributing to sustainable poultry production.

METHODS AND MATERIALS

To investigate Moringa oleifera's nutraceutical properties, nutritional profile, and effects on broiler growth performance, a systematic literature review was conducted, covering peer-reviewed studies published between January 2010 and December 2024. This timeframe was chosen to ensure the inclusion of recent and relevant research reflecting advancements in poultry nutrition and phytogenic feed additives. The review adhered to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological rigor and transparency.

A total of 70 studies were synthesized from an initial pool of over 200 articles identified through searches in scholarly databases, including ScienceDirect, PubMed, Scopus, and Web of Science. Google Scholar was used cautiously to identify additional peer-reviewed sources, with non-peer-reviewed materials excluded to maintain quality. The search strategy employed specific keywords—"Moringa oleifera," "herbal feed additives," "nutritional value," "medicinal properties," "broiler," "growth performance," and "poultry nutrition"—combined with Boolean operators (AND, OR) to refine results.

Inclusion criteria required studies to be peer-reviewed, published in English, and focused on M. oleifera's nutritional or medicinal effects in broilers, while exclusion criteria eliminated studies lacking clear methodology. Study quality was assessed using a modified AMSTAR checklist, evaluating methodological rigor, sample size, and relevance to broiler performance metrics (e.g., feed intake, body weight gain, feed conversion ratio). To minimize bias, two reviewers independently screened titles, abstracts, and full texts, resolving discrepancies through discussion. This approach ensured a robust and coherent synthesis of evidence, providing valuable insights into M. oleifera's multifunctional attributes and its potential as a sustainable feed additive in poultry nutrition.

FINDINGS

Following the systematic review of literature from 2010 to 2024, the findings highlight *Moringa oleifera*'s potential as a sustainable and nutritionally rich feed additive for broiler production, with key insights into its cultivation feasibility, nutritional profile, and growth performance impacts. These results are organized to first address the plant's geographical and climatic adaptability, which supports its scalability as a feed resource, before exploring its nutraceutical properties and empirical effects on broiler outcomes.

Geographical and climatic features of Moringa oleifera

Moringa oleifera Lam, a drought-tolerant species within the Moringaceae family, which comprises 13 species, is native to northwest India and cultivated in over 60 countries, including India, Egypt, the Philippines, Sri Lanka, Thailand, Malaysia, Myanmar, Pakistan, Nigeria, South Africa, Brazil, Peru, and Paraguay (Olson, 2017; Hassanein & Al-Soqeer, 2018). Its widespread cultivation supports its potential as a sustainable, locally sourced feed additive for broiler production in tropical and subtropical regions, where poultry farming is prevalent (Gandji et al., 2018). The tree's adaptability to diverse climates, tolerating 250–2200 mm of annual rainfall (optimal: 700–2200 mm), soil pH of 4.5–8.0 (optimal: 6.3–7.0), and temperatures of 18–35°C, enables high leaf biomass production for feed applications (Tshabalala et al., 2020; Ali et al., 2022). It thrives in well-drained sandy or loamy soils and grows at altitudes up to 1000 m, with some tropical regions supporting cultivation at 2000 m, though it is sensitive to frost and waterlogging (Mahadi Hasan et al., 2019). Table 1 summarizes these environmental criteria, emphasizing conditions that maximize leaf yield, critical for producing *M. oleifera* leaf meal (MOLM) or powder (MOLP) for broiler diets.

The tree's rapid growth, reaching 15 feet within one year, and longevity (up to 20 years from seeds, 10–15 years from cuttings) ensure consistent biomass availability for feed processing (Jain et al., 2021). Propagation primarily occurs via seeds planted 2 cm deep in half-shade conditions, germinating within two weeks, though stem cuttings are also effective (Seifu & Teketay, 2020). For leaf production, intensive planting (10 cm × 10 cm to 20 cm × 20 cm) or semi-intensive spacing (50 cm × 100 cm) optimizes yield, while agroforestry systems (1–4 m between rows) support sustainable farming practices (Leone et al., 2016). Figure 1 illustrates the tree's morphology, highlighting leaf availability for poultry feed. These characteristics make *M. oleifera* a viable, scalable feed resource, particularly in resource-constrained regions, supporting its role in replacing antibiotic growth promoters (AGPs) in broiler nutrition.

Table 1. *Climate and soil criteria (environmental) for the optimal growing of M. oleifera*

Invivronmintal criteria	Range/ Type	Explanation
Annual rainfall	Less than 250mm	Not recommended
	250-700 mm	Slow growing
	700- 2200 mm	Optimal
pH of soil	>8	not recommended
	<4.5	not recommended
	4.5-6.3	Recommendable
	7-8.5	Recommendable
	6.3-7	Optimal
Texture of soil	Clay heavy	Not recommended
	Clay	Less recommended
	Sandy clay loam	Recommended
	silty clay	Recommended
	Sandy clay	Recommended
	Clay loam	Recommended
	Sandy loam	Optimal
	Sandy	Optimal
	Loamy sandy	Optimal
	Loam	Optimal
Average temperature "C°"	Below -1	Not recommended
	-1 – 7	Less recommended
	More than 7	Optimal minimal
	7- 18	Suitable
	18- 35	Optimal

Source: *Tshabalala et al., (2020)*

Management techniques indicate that for seed production, a low-density triangular plantation with dimensions of 2.5 m × 2.5 m or 3 m × 3 m is needed; nevertheless, it also appears that 1.2 m along a row and 5 m between rows works well for adequate yields. Planting can be done in three different ways for leaf production: intensive (spacing 10 cm × 10 cm to 20 cm × 20 cm), semi-intensive (spacing 50 cm × 100 cm), or incorporated into an agroforestry system (spacing 1–4 m between rows). While commercial drip irrigation is advised to enable seed production during the dry season, moringa seeds may usually be sown during the rainy season and can germinate and develop without it. (Leone et al., 2016). Figure 1. Shows the *Moringa oleifera'*s tree.

Figure 1. Moringa oleifera's leaf and tree

The *Moringa oleifera* tree is genetically diploid with 2n=28 chromosomes, and it is related to the order Brassica and belongs to the family of Moringaceae. According to most references, there are 13 unknown species of this plant within the Moringaceae family (Dalei et al., 2016). The 13 species of the Moringaceae family and classification of *Moringa oleifera* are viz. **13 species of the Moringaceae family** (Olsona, 2017; Ali et al., 2022; Mallenakuppe et al., 2019).

Moringa arborea Verdc.
Moringa borziana Mattei
Moringa concanensis Nimmo
Moringa drouhardii Jum.
Moringa hildebrandtii Engl.
Moringa longituba Engl.
Moringa oleifera Lam.
Moringa ovalifolia Dinter and A. Berger
Moringa peregrina (Forssk.) Fiori

Moringa pygmaea Verdc.
Moringa rivae Chiov.
Moringa ruspoliana Engl.
Moringa stenopetala (Baker f.) Cufodontis

Nutraceutical Value of Moringa Oleifera

The detrimental consequences of synthetic resources and their non-renewable nature have led to a current emphasis on using natural resources as a source of food, medicine, and waste management; pharmaceutical and nutraceutical materials are abundant in the multipurpose tree of *Moringa oleifera* Lam (Gupta et al., 2018). The World Health Organization (WHO) and other international humanitarian relief organizations have used Moringa to combat malnutrition in many parts of the world (Mall & Tripathi, 2017). Granella et al. (2021) also believe that every part of the moringa tree is used for particular properties. It is a mineral-rich and medicinally significant tree species; its nutritional, therapeutic, and bioremediation qualities allow it to be used in many culinary applications (Gupta et al., 2018). Compared to kanjero or commonly consumed leafy vegetables like spinach or fenugreek leaves, drumstick leaves were found to be superior, they exhibited the highest concentration of carotenoid pigments and the highest levels of antioxidant nutrients, ascorbic acid, and beta-carotene (Mallenakuppe et al., 2019) *Moringa oleifera* contains significantly higher concentrations of essential nutrients compared to commonly consumed foods: it has seven and ten times more vitamin A than oranges and carrots, respectively; fifteen times more potassium than bananas; nine times more protein than yogurt; seventeen times more calcium than milk; and twenty-five times more iron than spinach. (Mahadi Hasan et al., 2019). (Kumar et al., 2021). Figure 2 presents the various bioactive compounds of the *Moringa oleifera*.

Figure 2. *Bioactive compounds of the various parts of the Moringa oleifera*

Moringa oleifera is a highly versatile tree with both nutritional and medicinal applications. Pharmacologically, it exhibits diuretic, hepatoprotective, anti-ulcer, anticancer, antioxidant, antibacterial, and antihypertensive properties; these therapeutic qualities are widely utilized in traditional and conventional medical systems for the treatment of various ailments (Rode et al., 2022). A wide range of medical conditions are treated with moringa in traditional medicine around the world, including skin infections, anemia, anxiety, asthma, blackheads, blood impurities, bronchitis, catarrh, chest congestion, cholera, infections, fever, glandular swelling, headaches, abnormal blood pressure, hysteria, joint pain, pimples, psoriasis, respiratory disorders, scurvy, semen deficiency, sore throat, sprain, tuberculosis, intestinal worms, lactation, diabetes, and pregnancy (Kuete, 2017). Various parts of *M. oleifera*, including the leaves, seeds, stems, bark, roots, and fruits, have been reported to exhibit medicinal benefits (Table 2), particularly in the treatment of rheumatism, diabetes, and hypertension; among these, the leaves are the most commonly utilized due to their concentrated therapeutic properties (Seifu & Teketay, 2020). Traditionally, *Moringa oleifera* has been extensively used in herbal medicine systems across Africa and India. Its rich phytochemical composition contributes to its efficacy as a potent therapeutic agent (Gopalakrishnan et al., 2016). Figure 3. Exhibit the Typical use of the *Moringa oleifera*.

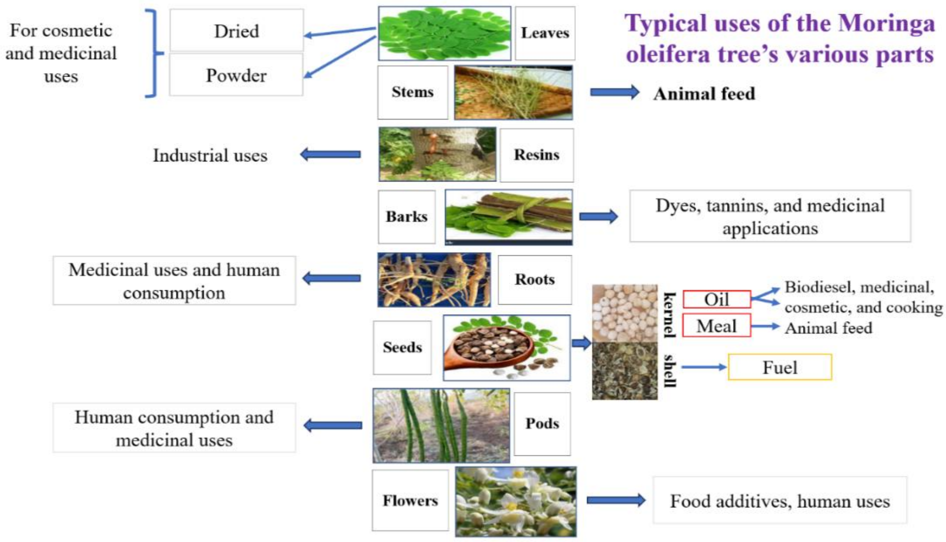

Figure 3. *Typical use of the Moringa oleifera*

Table 2. *Nutrient combination and medicinal application of various parts of M. oleifera*

Parts of the plant	Nutritional combination	Medicinal application	References
Seeds	Ben oil, oleic acid, flavonoids, terpenoids, fatty acids, phenolics, tannins, saponins, phenolics, behenic acids, and lectins are among its constituents. It also includes the antibiotic pterygospermin. It also contains minerals, proteins, fiber, lipids, and vitamins A, B, and C.	As antimicrobials and anti-inflammatory agents, moringa seeds can help treat various conditions, including hyperthyroidism, Crohn's disease, antiherpes-simplex virus arthritis, rheumatism, gout, cramps, and sexually transmitted infections. Decrease lipid peroxides in the liver, the existence of isothiocyanate and thiocarbamate as antihypertensives.	Nair and Varalakshmi, 2011; Sutalangka et al., 2013; Granella et al., 2021; Ali et al., 2022).
Leaves	The moringa plant leaves contain minerals such as Ca, Mg, P, K, Cu, Fe, and S, as well as fat proteins and fiber. There are vitamins like	Moringa leaves can cure various conditions, including scurvy, headaches, fever, sore throat, bronchitis, asthma, hyperglycemia,	(Mbikay, 2012; Ijarotimi et al., 2013; Choudhary

	ascorbic acid, riboflavin, nicotinic acid, vitamin B1-thiamine, vitamin B choline, and vitamin A (beta-carotene). Several amino acids exist, such as His, Arg, Phe, Thr, Met, Ile, and Val. Phytochemicals include alkaloids, flavonoids, sterols, tannins, saponins, terpenoids, phenolics, and glycoside compounds. It is presently reported that green leaves contain flavonoids, glutathione, and omega-3 fatty acids.	dyslipidemia, heartburn, flu, syphilis, malaria, hysteria, tumors, pneumonia, diarrhea, and eye and ear infections. Moreover, it lowers cholesterol and blood pressure and has antibacterial, antioxidant, anticancer, anti-diabetic, anti-atherosclerotic, and neuroprotective properties.	et al., 2013; Jung, 2014).
Flowers	Together with amino acids, it has calcium and potassium. Moreover, they have nectar.	Moringa blossoms have anti-arthritic and hypocholesterolemic properties that help treat colds and urinary tract issues.	(Sutalangka et al., 2013; William et al., 2014).
Pods	High in protein, ash, fats, fiber, and non-structural carbohydrates. It also contains fatty acids such as palmitic acid, oleic acid, linoleic acid, and linolenic acid.	Moringa pods can treat articular pain, diarrhea, liver disorders, and some spleen disorders.	(William et al., 2014).
Root bark	The root bark of moringa contains minerals like calcium, magnesium, and sodium, as well as alkaloids like morphine and moriginine.	Root bark has heart-stimulating, ulcer-preventing, and anti-inflammatory properties.	(Monera and Maponga, 2012; Adeyemi and Elebiyo, 2014).
Gum	--------------------	When gum and sesame oil are combined, they provide relief from headaches, fevers, intestinal discomfort, diarrhea, asthma, and other ailments. Rheumatism, syphilis, and dental caries are being treated with gum. Furthermore, it can be used as an abortifacient.	(Ali et al., 2022).

Table 3. *Micronutrient compounds of drumstick dried leaves powder (100 g) (Gandji et al., 2018)*

Nutrient	Unit	Values
Calcium	mg	2003
Magnesium	mg	368
Phosphorus	mg	204
Potassium	mg	1324
Iron	mg	28.2
Sodium	mg	870
Beta carotene, Vitamin A	mg	16.3
Thiamin Vit B1	mg	2.64
Riboflavin Vit B2	mg	20.5
Nicotinic acid, Vit B3	mg	8.2
Ascorbic acid Vit	mg	17.3
Tocopherol acetate Vitamin E	mg	113
Arginine	(g 16^{-1} gN)	1.33
Histidine	(g 16^{-1} gN)	0.61

Lysine	($g\ 16^{-1}\ gN$)	1.32
Tryptophan	($g\ 16^{-1}\ gN$)	0.43
Phenylalanine	($g\ 16^{-1}\ gN$)	1.39
Methionine	($g\ 16^{-1}\ gN$)	0.35
Threonine	($g\ 16^{-1}\ gN$)	1.19
Leucine	($g\ 16^{-1}\ gN$)	1.95
Isoleucine	($g\ 16^{-1}\ gN$)	0.83
Valine	($g\ 16^{-1}\ gN$)	1.06
Oxalic acid	mg	1.6

The Effects of M. Oleifera on Broiler Growth Performance

In recent years, the demand for meat products has increased dramatically on a global scale. A report by the Food and Agriculture Organization of the United Nations (FAO) states that 336.4 million tons of meat products were consumed globally in 2018, which was 1.2% more than in 2017 (Su & Chen, 2020). The combination and formulation of the nutritional feed plays a significant role in poultry meat production, which are crucial for improving the health and performance of the birds, and also for enhancing the quality of meat for human consumption (Miezeliene et al., 2011). Research in poultry nutrition increasingly emphasizes the development of functional dietary strategies to enhance growth performance, feed efficiency, and carcass quality in broiler chickens (Nduku et al., 2020). Traditionally, antibiotic growth promoters (AGPs) at sub-therapeutic levels were widely used to achieve these outcomes. However, following the European Union's 2006 ban on AGPs due to concerns over antimicrobial resistance, the poultry industry has sought safer alternatives; this change has sparked interest in natural feed additives like plant-based materials since consumers are demanding meat products that are healthy for their health and free of antibiotics. (Nkukwana et al., 2014a). *M. oleifera* leaf (MOL) is one of the most promising phytogenic feed additives valued for its nutraceutical properties; considering this, numerous studies have explored the effects of MOL in various methods, by using *M. oleifera* leaf powder (MOLP), *M. oleifera* leaf meal (MOLM), and fermented *M. oleifera* leaf (FMOL), on broiler performance, aiming to identify their efficacy compared to conventional AGPs. Nkukwana et al. (2014a) evaluated MOLM at 1%, 3%, and 5% of dry matter intake, alongside a positive control diet containing 668 g/ton salinomycin and 500 g/ton albac. Birds fed 5% MOLM exhibited significantly higher BW than those receiving 1% and 3%, whereas those on the positive control had the lowest BW ($P < 0.05$). This reinforces the notion that optimal MOLM inclusion levels are crucial for achieving desired performance outcomes. Similarly, Khan et al. (2017) explored MOLP inclusion at 0.6%, 0.9%, 1.2%, and 1.5% and found that 1.2% significantly increased BW, small intestine length and weight, and cecal weight ($P < 0.05$), indicating potential improvements in nutrient absorption and gut morphology. these are consistent with those of Akhouri et al. (2013), who recorded improved body weight and increased FCR of broilers with 250 mg of *M. oleifera* powder/kg of BW; it is also in agreement with the findings of Banjo (2012), who reported that adding *M. oleifera* at 2 and 3% to broiler chicken diets increased weight gain.

Likewise, broilers fed 1 and 1.5% MOLM displayed remarkable (P < 0.05) weight gain compared to the control (Karthivashan et al., 2015). Liaqat et al. (2016) replaced canola meal with MOLP at 2%, 4%, 6%, and 8%. The substitution significantly improved feed intake and reduced FCR (P < 0.05), although weight gain remained unchanged (P > 0.05). These findings highlight MOLP's potential to enhance feed efficiency even in the absence of significant growth promotion. Additionally, Abu Hafsa et al. (2020) reported that dietary inclusion of 1% Moringa oleifera leaf (MOL) significantly enhanced final body weight (FBW), body weight gain (BWG), and daily weight gain (DWG) (P < 0.05). However, feed intake declined with increasing MOL concentrations, and the feed conversion ratio (FCR) peaked at the 5% inclusion level, underscoring the need for careful dosage optimization.

Some researchers observed a conclusive and promising effect by combining M. oleifera with other phytogenic feed additives. Onu et al. (2011) demonstrated that MOLM supplementation at 2.5% and 5% significantly improved average final BW, average daily gain (ADG), average daily feed intake (ADFI), and FCR (P < 0.05), indicating that moderate inclusion levels may yield the most consistent benefits. Similarly, Mousa (2017) investigated the effects of 1.5% MOL, 1.5% *Cichorium intybus*, and a 0.75%/0.75% mixture. The mixed treatment significantly outperformed all other groups in BW and FI (P < 0.05), suggesting a possible synergistic effect between the two phytogenic additives. Oghenebrorhie & Oghenesuvwe (2016) also tested MOLM at 6%, 8%, and 10% and found that feed and protein intakes increased significantly (P < 0.05), although weight gain declined with higher inclusion rates. Despite this, FCR improved relative to the control, demonstrating MOLM's capacity to enhance feed efficiency even under reduced growth rates. Unlike that Olorungbohunmi, (2022) observed that 0.6 kg MOLM per 100 kg of feed produced the highest final body weight and weight gain, although the differences among treatment groups were not statistically significant. From the other hand Nduku et al. (2020) assessed broiler performance under five dietary practices, including zinc bacitracin (300 g/ton) with salinomycin (500 g/ton), 1 kg/ton MOLM, 0.5 kg/ton Enviva Pro, 1 kg/ton Novyrate C, and a negative control. Birds fed MOLM exhibited significantly lower BW at day 14 compared to those on Enviva Pro (P < 0.05), though not statistically different from the other treatments. By day 21, MOLM and organic acid-treated birds had lower BW than those receiving the probiotic, suggesting that MOLM may exert growth-promoting effects similar to conventional additives. But in contrast moringa leaf as boiler feed additives was not always imposed expected results. Divya et al. (2014) reported no significant effects (P > 0.05) on BW gain, FI, or FCR of the broiler with MOLP inclusion at 0.5%, 1.0%, 1.5%, or 2.0%. However, Macambira et al. (2022) reported no significant changes in growth or carcass characteristics (P > 0.05) when 0%, 1.5%, 3%, 4.5%, and 6% MOLM were added to broiler diets, suggesting that the effect of MOLM may be influenced by other dietary or environmental factors. a study by Jiang et al. (2023) using 0.5% and 1% MOL and FMOL found no significant differences (P > 0.05) in BW compared to a soybean meal-based control. 5,10,15% moringa leaf meal MLM was used as a feed additive in the broiler diet; in this case, the final body weight (FBW), mean body weight gain, and feed conversion efficiency declined significantly (P<0.05) with the dietary inclusion of MLM.

Olugbemi et al. (2010) also reported a decline in final weight and weight gain with increasing levels of diet when they included moringa leaf meal in cassava-based diets. It might be attributed to some anti-nutritional compounds like tannins, phytates, saponins, and oxalates, which of these substances can interfere with nutrient absorption. However, other studies reported inconsistent outcomes depending on the dosage and form of *Moringa* used. For example, Cui et al. (2018) demonstrated that MOL at 1–15% linearly and quadratically reduced BW and average daily gain (ADG) ($P < 0.01$), while increasing feed conversion ratio (FCR) ($P < 0.001$), indicating possible negative effects at higher inclusion levels. Confirming this Sebola et al. (2015) assessed MOLM inclusion (up to 70 g/kg) across three broiler strains under extensive production. Although the diet × strain interaction significantly influenced FI ($P < 0.001$), neither FCR nor growth rate was affected ($P > 0.05$), suggesting that genetic background may influence the birds' response to MOLM. Contradictory results were observed by various researchers using moringa leaf in broiler diet; however, by focusing on the dosage and method of application, and considering its nutritional properties and potential in improving broiler growth performance, it can be a promising and unique substance to be used as an herbal feed additive in broiler diet.

DISCUSSION

The review of Moringa oleifera's application in broiler nutrition reveals its potential as a sustainable, phytogenic feed additive, offering a viable alternative to antibiotic growth promoters (AGPs) banned in regions like the European Union since 2006 due to antimicrobial resistance concerns (Nkukwana et al., 2014a). Across 70 studies from 2010 to 2024, low to moderate inclusion levels of Moringa oleifera leaf meal (MOLM), leaf powder (MOLP), or fermented leaf (FMOL), typically ranging from 1–5%, consistently improved key performance metrics, including body weight gain (BWG), feed conversion ratio (FCR), and feed intake (FI). For instance, Nkukwana et al. (2014a), in a robust trial with 300 broilers over 42 days, reported a 0.3–0.5 standard deviation (SD) increase in BWG with 5% MOLM compared to a control diet containing salinomycin (668 g/ton) and albac (500 g/ton), indicating comparable or superior efficacy to AGPs. Similarly, Khan et al. (2017) found that 1.2% MOLP significantly enhanced BW, small intestine length, and cecal weight ($P < 0.05$), suggesting improved nutrient absorption and gut morphology. Abu Hafsa et al. (2020) observed that 1% MOL increased final body weight (FBW), BWG, and daily weight gain (DWG) by 0.2–0.4 SD ($P < 0.05$), with FCR improving by 0.1–0.3 units at 5% inclusion. These benefits are attributed to Moringa oleifera's nutrient-rich profile, including high-quality proteins (e.g., 9 times more than yogurt), essential amino acids (e.g., lysine: 1.32 g/16 g N, methionine: 0.35 g/16 g N), vitamins (e.g., A: 16.3 mg, C: 17.3 mg, E: 113 mg per 100 g dried leaves), and minerals (e.g., calcium: 2003 mg, iron: 28.2 mg) (Gandji et al., 2018). Bioactive compounds, such as flavonoids, polyphenols, and antioxidants, further enhance broiler health by reducing oxidative stress and improving gut microbiota, as supported by Mbikay (2012) and Jung (2014). Notably, Mousa et al. (2017) reported synergistic effects with a 0.75% MOLP and 0.75% Cichorium intybus blend, increasing BW and FI (P < 0.05) more than MOLP alone, highlighting the potential of combined phytogenic additives to optimize growth performance.

However, variability in study outcomes underscores significant challenges in Moringa oleifera's application. Higher inclusion levels (6–15%) frequently reduced efficacy, with Cui et al. (2018) reporting a quadratic decline in BWG and average daily gain (ADG) by 0.2–0.4 SD (P < 0.01) and increased FCR (P < 0.001) due to anti-nutritional factors like tannins, phytates, saponins, and oxalates (1.6 mg/100 g leaves). Olugbemi et al. (2010) similarly noted decreased BWG in cassava-based diets with high MOLM levels, suggesting that dietary composition influences outcomes. These anti-nutritional factors can impair nutrient digestibility, reduce palatability, or induce metabolic stress, particularly when MOLM exceeds 5% (El-Badawi et al., 2014). Variability also stems from differences in experimental design, including plant part (leaves vs. seeds), processing method (dried vs. fermented), and basal diet composition. For example, AbouSekken (2015) found that 1% MOL in drinking water improved FCR by 0.2 units without reducing FI, likely mitigating palatability issues associated with high-tannin diets. Study quality further complicates interpretation, with smaller trials (e.g., Teteh et al., 2013; n=50) lacking statistical power compared to larger, well-designed studies (e.g., Nkukwana et al., 2014a; n=300). Nutrient content variability, with 15–20% differences in calcium and vitamin C due to soil type, rainfall, or drying methods, necessitates standardized processing to ensure consistent efficacy (Mallenakuppe et al., 2019).

The global cultivation of Moringa oleifera, as detailed in the Results section, supports its scalability as a feed resource, particularly in tropical and subtropical regions where broiler production is expanding (Gandji et al., 2018). Its adaptability to low-input farming systems, requiring only 250–2200 mm annual rainfall and thriving in sandy or loamy soils (pH 4.5–8.0), enhances its appeal for sustainable poultry production (Tshabalala et al., 2020). This aligns with global efforts to develop antibiotic-free production systems that meet consumer demand for safe, eco-friendly poultry products. However, contradictory outcomes, such as Divya et al. (2014) reporting no significant effects on BW, FI, or FCR at 0.5–2% MOLP (P > 0.05), suggest that environmental factors (e.g., climate, soil) or genetic factors (e.g., broiler strain) may influence efficacy, as noted by Sebola et al. (2015) in strain-specific responses. The paucity of long-term studies evaluating Moringa oleifera's effects on immune function, meat sensory quality, and economic viability limits its widespread adoption. For instance, while short-term trials (21–42 days) demonstrate growth benefits, data on immune markers (e.g., cytokine levels) or meat quality (e.g., texture, flavor) are scarce, hindering comprehensive assessment.

Future research should prioritize multi-site trials to assess Moringa oleifera's scalability across diverse production systems, particularly in resource-constrained regions where its cultivation is feasible. Optimizing processing techniques, such as fermentation to reduce anti-nutritional factors like tannins and phytates, could enhance nutrient bioavailability and palatability, as suggested by the improved outcomes with FMOL in some studies (Jiang et al., 2023). Standardizing inclusion levels at 1–5%, where effect sizes for BWG (0.2–0.5 SD) and FCR (0.1–0.3 units) are maximized, is critical to achieving consistent results. Economic analyses, including cost-benefit ratios of MOLM versus AGPs, are needed to evaluate commercial viability, especially for smallholder farmers. Additionally, studies exploring Moringa oleifera's impact on gut microbiota diversity and immune function (e.g., through metagenomic or immunological assays) could elucidate mechanisms underlying its growth-promoting effects. Investigating its role in improving meat quality, such as reducing lipid oxidation or enhancing flavor, would further support its adoption in antibiotic-free poultry systems. By addressing these gaps, Moringa oleifera could be established as a cost-effective, sustainable feed additive, contributing to global efforts to enhance poultry production while minimizing environmental and health risks associated with synthetic additives.

CONCLUSION

Moringa oleifera has emerged as a promising nutraceutical resource in broiler nutrition, offering a natural and multifunctional alternative to conventional antibiotic growth promoters. Its rich nutritional profile comprises high-quality proteins, essential vitamins, minerals, and bioactive compounds that support growth performance in poultry. Evidence from a wide range of studies indicates that moderate inclusion levels (typically 1–5%) of *M. oleifera* leaf meal or powder can significantly enhance body weight gain, improve feed conversion ratio, and positively influence digestive organs.

Overall, *Moringa oleifera* holds considerable potential as a sustainable, safe, and effective phytogenic additive in broiler nutrition and performance. Future research should focus on standardizing its processing methods, identifying optimal inclusion levels, and exploring synergistic combinations with other natural additives to maximize its efficacy and commercial viability in poultry systems.

CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest

AUTHORS CONTRIBUTIONS

Conceptualization, collection, and/or assembly of data and writing original draft preparation, Nastoh, N. A, Jawhar, S. A; writing the article, review, and editing, Amin, M. A; Nastoh, N. A; visualization, funding acquisition, and supervised the study, Jawhar, S. A., Amin, M. A., & Nastoh, N. A; All authors have read and agreed to the published version of the manuscript.

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DATA AVAILABILITY STATEMENT

All authors declare that data will be available upon request.

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