


# Pharmacological, nutritional and antimicrobial uses of *Moringa oleifera* Lam. leaves in poultry nutrition: an updated knowledge

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**ABSTRACT** Recently, developing countries have focused on using innovative feed in poultry nutrition. The plant *Moringa oleifera* is native to India but grows worldwide in tropical and subtropical climates. Moringa is planted on a large scale as it can tolerate severe dry and cold conditions. All parts of this plant can be used for commercial or nutritional purposes, and it has a favorable nutritional profile. Beneficial phytochemicals, minerals, and vitamins are abundant in the leaves. The leaf extracts can be used to treat malnutrition; they also possess anti-cancer, antioxidant, antidiabetic, antibacterial, and anti-

inflammatory properties. Further, moringa contains anti-nutritional substances, such as trypsin inhibitors, phytates, tannins, oxalates, cyanide, and saponins, which have a harmful effect on mineral and protein metabolism. Previous research suggested that including moringa in chicken diets boosts their growth and productivity. Therefore, this review focuses on the characterization and application of *M. oleifera* in poultry nutrition and its potential toxicity. Furthermore, we discuss the nutritional content, phytochemicals, and antioxidants of *M. oleifera* leaf meal and its applicability in poultry rations.

**Key words:** antioxidants, antibiotic alternatives, antimicrobials, *Moringa oleifera*, organic poultry

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## INTRODUCTION

Poultry products are rich sources of various proteins and minerals (Abd El-Hack et al., 2022a,b). However, several environmental hazards, such as heat stress and infectious agents (viral, bacterial, parasitic, and fungal pathogens), threaten the poultry industry worldwide,

causing severe economic losses (El-Shall et al., 2022; Salem et al., 2022a,b). Currently, using natural antibiotic alternatives to improve poultry production and avoid the residual impact of antibiotic use in poultry products is considered a global initiative (Abd El-Hack et al., 2016a; Rehman et al., 2020).

Probiotics, prebiotics, synbiotics, amino acids, herbal extracts, exogenous enzymes, essential oils, green synthesized nanoparticles, and phytochemical products are the most common natural feed additives used to improve the production of poultry and livestock (Abou-Kassem et al., 2021, 2022; Alagawany et al., 2021; Arif et al., 2022). Various phytochemical poultry feed additives, such

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as aromatic herbs or fragrance oils, have also been explored in the recent decades (Ahossi et al., 2016; Abd Elkader et al., 2021; Reda et al., 2021). Indeed, their premium varieties are validated at different inclusion levels to identify nutritional supplements that are natural, inexpensive, and safe and provide high financial returns (Cross et al., 2007; Abd El-Hack et al., 2021a,b,d, Abd El-Hack et al., 2022d).

*Moringa oleifera* is a member of the family Moringaceae that originated in several countries, including southern Asia, and has now spread to the tropical and subtropical regions of the world (Fahey, 2005). *Moringa* has been used by the ancient Greeks and Romans (Duke, 2001). *M. oleifera* was introduced to Kenya by Indians during the construction of the Kenya–Uganda railway, and it is currently grown in Kenyan rangelands, including the lower Eastern, Baringo, and the Coast regions (Maundu and Tegnas, 2005). *Moringa* is a perennial shrub that grows well in a wide variety of soils, especially in sandy loams and slightly alkaline clay soils because of their good drainage ability (Abdul, 2007). It thrives best at altitudes of 0 to 1,800 m above sea level, with an annual rainfall of 500 to 1,500 mm (Sánchez et al., 2006; Nouman et al., 2014). Therefore, it is suitable for tropical and subtropical regions that are characterized by hot, humid, and dry climate and provides ample nutritional value even under marginal growth conditions (Nouman et al., 2014).

*M. oleifera* has high biomass yields of 4.2 to 8.3 metric tons/hectare (ha). Biomass and leaf nutritional composition are influenced by seasons; planting density; soil factors, such as fertilizer use, irrigation, and harvesting frequencies (Sánchez et al., 2006; Radovich, 2011). Similar to fodder shrubs, considerable time is required for the establishment of *M. oleifera* for strong root growth before the first defoliation. This period is approximately 1 yr when *M. oleifera* grows up to 1 to 1.5 m in height (Sánchez et al., 2006). Makkar and Becker (1997) documented that the appropriate plant spacing for the optimal performance of *M. oleifera* ranges from 1 m × 1 m (10,000 plants per ha) to 2.50 cm × 2.50 cm (16,000,000 plants per ha).

The total yield of fresh (FM) and dry matter (DM), growth rate, and height of *M. oleifera* during the first and second years increase significantly as the cutting interval is increased from 45 to 75 d (Sánchez et al., 2006). The same authors reported that during the first year of growth, DM, neutral detergent fiber (NDF), and ash contents were highest and the *in vitro* digestibility was lowest at the longest harvesting frequency, whereas crude protein (CP) and acid detergent fiber (ADF) contents were not affected by the harvesting frequency. For intensive biomass production, it is recommended that *M. oleifera* should be densely planted, with 50 to 75 plants per square meter, and harvested every 75 d (Sánchez et al., 2006).

The concentration of fragrant plant parts in the feed increased from 100 to 30,000 mg/kg. In layer diets, anise seed powder was used at a concentration of 250 to 1,500 mg/kg and rosemary powder were used at 400 to

500 mg/kg (Botsoglou et al., 2005). In addition, Cross et al. (2007) used marjoram, rosemary, and yarrow powder in broiler diets at 10,000 mg/kg. Furthermore, Govaris et al. (2007) added rosemary powder to turkey diets at 5,000 to 10,000 mg/kg. Christaki et al. (2011) supplemented the laying Japanese quail diet with oregano at 10,000 to 30,000 mg/kg. These diets resulted in significant benefits to chicken health and productivity.

Small inclusions of volatile oils in the feed showed a similar level of influence as other plant parts at higher concentrations. Some examples include herbal essential oils, such as thyme, marjoram, rosemary, and yarrow oil, at a concentration of 1,000 mg/kg (Cross et al., 2007) and oregano essential oils at 50 to 300 mg/kg (Botsoglou et al., 2002; Giannenas et al., 2003; Govaris et al., 2005). Ciftci et al. (2005) used aniseed oil at 100 to 400 mg/kg, Lopez-Bote et al. (1998) used rosemary extracts and sage at 500 mg/kg, and Amerah et al. (2011) used thymol and cinnamaldehyde at 100 mg/kg.

Feed quality can be improved by incorporating phyto-genic substances (Abdelnour et al., 2020a,b; Ashour et al., 2020). First, these substances can inhibit the growth of mycotoxigenic fungi (Soliman and Badea, 2002). Second, the antibacterial and antioxidant properties of phyto-genic substances, such as carvacrol, rosmarinic acid, and thymol, are critical factors for improving the overall feed quality (Burtis and Bucar, 2000). The antioxidant quality may be essential when the feed contains a higher amount of polyunsaturated fatty acids than saturated fatty acids. It has been suggested that the antimycotic properties of phyto-genic extracts/essential oils are responsible for the prevention of mycotoxin formation in stored wheat grains. These substances could act as antioxidant, antispasmodic, immunomodulatory, antimicrobial, anti-inflammatory, and anticancer agents. They can also promote the production of intestinal flora and enhance digestion, absorption, and nutrient metabolic activity (Abd El-Hack et al., 2016b, 2018; Arif et al., 2019; Ashour et al., 2020). Abd El-Hack and Alagawany (2015) and Abd El-Hack et al. (2016a) reported that anise, thyme, and cinnamon prevent the development of toxigenic fungi, such as *Fusarium moniliforme*, *Aspergillus parasiticus*, *Aspergillus flavus*, and *Aspergillus ochraceus*.

This review article provides additional information on the nature, nutritional benefits, and prospective use of *M. oleifera* as a chicken feed additive.

## Description of *M. oleifera*

*M. oleifera* is also known as drumstick tree, ben oil tree, benzoyl tree, and horseradish tree. The leaves, pods, seeds, flowers, fruits, and roots of the moringa tree are edible (Orwa et al., 2009). The family Moringaceae comprises 13 species (Table 1).

Several studies have been conducted on the nutritional composition of *M. oleifera* in different geographical locations. The leaves of *M. oleifera* contain Calcium (Ca) 99.1mg, Phosphorous (P) 70.8, Magnesium (Mg) 35.1, Iron (Fe) 1.3, Zinc (Zn) 0.85, Sodium (Na) 70, Manganese (Mn) 0.119, and Potassium (K) 471mg in

**Table 1.** Species of the family Moringaceae.

Species name	Properties
<i>Moringa hildebrandtii</i>	Medicinal
<i>Moringa drouhardii</i>	Medicinal
<i>Moringa stenopetala</i>	Edible delicious leafs
<i>Moringa ovalifolia</i> “aka ghost tree”	Medicinal
<i>Moringa peregrina</i>	Edible
<i>Moringa oleifera</i>	Edible delicious leaves
<i>Moringa concanensis</i>	Edible leaves
<i>Moringa rivae</i>	Medicinal
<i>Moringa ruspoliana</i>	Medicinal
<i>Moringa arborea</i>	Medicinal
<i>Moringa borziana</i>	Medicinal
<i>Moringa pygmaea</i>	Medicinal
<i>Moringa longituba</i>	Medicinal

DM (Abbas et al., 2018). Because of its rich nutritional composition, *M. oleifera* is used in human and animal feeds and for medicinal purposes (Richter et al., 2003; Sánchez et al., 2006). *M. oleifera* leaves contain high levels of soluble carbohydrates (10%) and  $\beta$ -carotenes ( $2.33 \times 10^2 \mu\text{g/L}$ ) (Mustapha and Babura, 2009).

*M. oleifera* is also rich in tocopherols ( $\gamma$  and  $\alpha$ ), phenolic compounds, vitamin C, essential sulfur amino acids (methionine and cysteine), unsaturated fatty acids (oleic acids), and minerals (Ferreira et al., 2008; Mustapha and Babura, 2009). Furthermore, these leaves have a high total antioxidant capacity (260 mg/100 g) and high levels of total polyphenols (260 mg/100 g), quercetin (100 mg/100 g), kaempferol (34 mg/100 g), and  $\beta$ -carotene (34 mg/100 g) (Lako et al., 2007). *M. oleifera* seeds contain high levels of stable oleic acids followed by palmitic acids and behenic acids (Sánchez-Machado et al., 2015). The nutritional contents of each part of the *M. oleifera* tree are summarized in Figure 1. *M. oleifera*

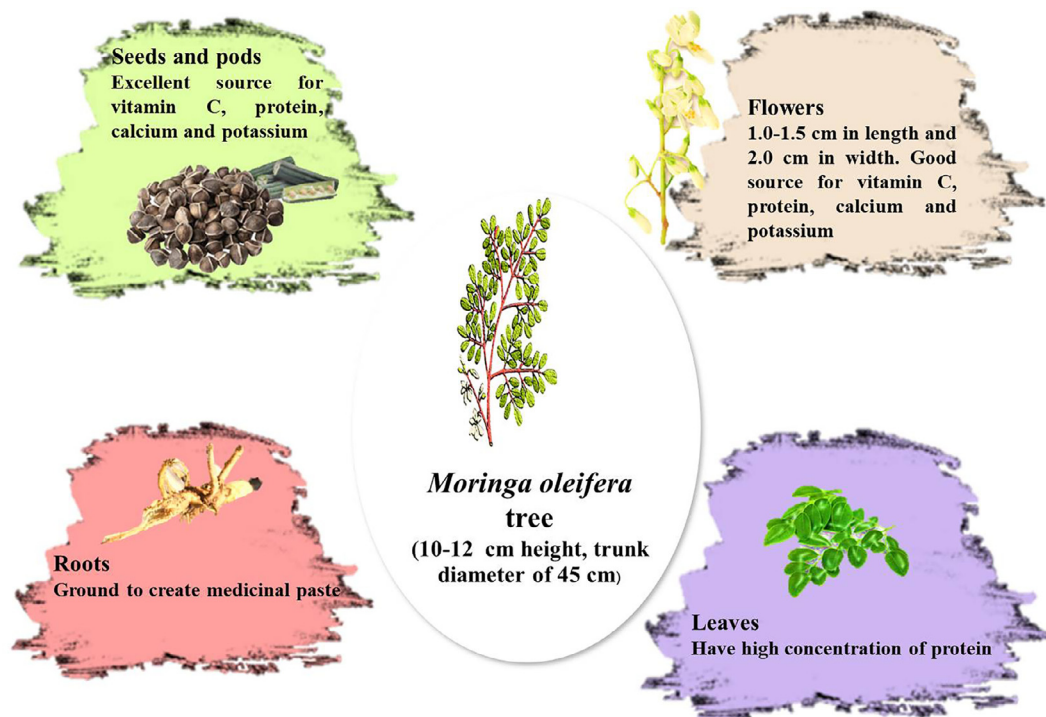
possesses a wide range of biological activities, including antioxidant, tissue protective (liver, kidneys, heart, testes, and lungs), analgesic, antiulcer, antihypertensive, radioprotective, and immunomodulatory properties in addition to being an important nutritional agent (Stojs and Hartman, 2015; Okumu et al., 2017).

*M. oleifera* is a deciduous tree that can quickly grow up to 10 to 12 m in height, and the diameter of its trunk is approximately 45 cm. The flowers are approximately 1.0 to 1.5 cm long and 2.0 cm wide. The flowering process begins within 6 months of transplantation. The fruit is a brown, 3-sided pendulous capsule with a diameter of 20 to 45 cm that contains dark brown globular seeds (1 cm in diameter). The seeds are dispersed by 3 thin whitish wings through water and wind (Olson and Carlquist, 2001). The tree requires an average annual rainfall of 250 to 3,000 mm and can be sustained at temperatures between 25°C and 40°C, which is ideal for tropical regions.

### Nutritional Composition of *M. oleifera* Leaves

Moringa leaves are rich in iron, protein, carotenoids, and ascorbic acid (Table 2). In terms of highly digestible nutrients, the consumption of *M. oleifera* leaves is encouraged in several underdeveloped nations worldwide, where they may be consumed in fresh or roasted forms or preserved as a dry powder (Fahey, 2005). *M. oleifera* leaves could be used as a food additive to improve feed intake and animal profitability. Alternatively, they could substitute traditional harvests for more effective economic, ecofriendly, and safe production (Aregheore, 2002; Richter et al., 2003).

Rubanza et al. (2005) found improved feed absorption in animals fed with *M. oleifera* leaves, which was



**Figure 1.** The nutritional contents of each part of *Moringa oleifera* tree.

**Table 2.** Mineral contents of dried *Moringa oleifera* leaves (source: [Moyo et al. \(2011\)](#)).

Mineral	Dry leaves
Calcium (Ca) (%)	3.65
Phosphorus (P) (%)	0.30
Magnesium (Mg) (%)	0.50
Potassium (K) (%)	1.50
Sodium (Na) (%)	0.164
Sulphur (S) (%)	0.63
Zinc (Zn) (mg/kg)	31.03
Copper (Cu) (mg/kg)	8.25
Iron (Fe) (mg/kg)	490
Manganese (Mn) (mg/kg)	86.8
Selenium (Se) (mg/kg)	36.30
Boron (B) (mg/kg)	49.93

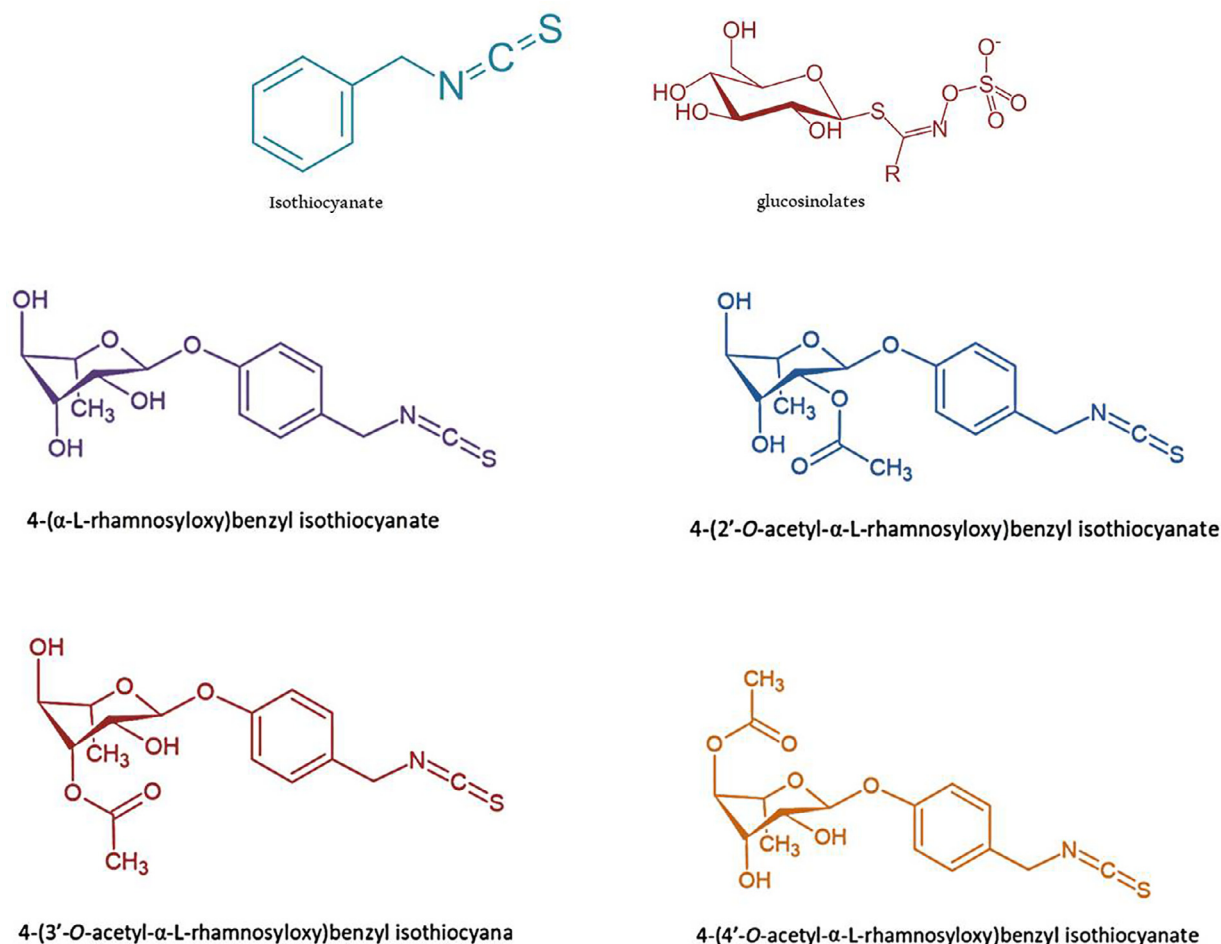
attributed to the plant's superior nutritional profile, particularly amino acids, CP, NDF, ADF, and ether extract. Toxins and other antinutritional substances are present in some parts of *M. oleifera*, rendering them unfit for human or animal consumption. Alkaloids, tannins, saponins, and inhibitors abound in the tree's bark ([Becker and Makkar, 1999](#); [Foidl et al., 2001](#)). Therefore, it has been recommended that more attention should be paid to the leaf nutritional composition of moringa because they are used for rations, particularly in carp nutrition ([Becker and Makkar, 1999](#)). Antinutritional substances, such as tannins, saponins, and

alkaloids, can obstruct digestive enzymes and reduce feed usage ([Foidl et al., 2001](#)).

## Phytochemicals in *M. oleifera* Leaves

The phytochemical analyses of *M. oleifera* leaves revealed several unusual chemicals, including rhamnose, glucosinolates, and isothiocyanate ([Fahey et al., 2001](#); [Bennett et al., 2003](#)). Leaves also contain benzyl glucosinolates, 4-( $\alpha$ -L-rhamnopyranosyloxy)-benzylisothiocyanate, and 4-(4'-Oacetyl- $\alpha$ -L-rhamnopyranosyloxy) benzylthiocyanate. These compounds exhibit anticancer, hypotensive, and antibacterial properties ([Fahey et al., 2001](#)). The chemical structures of *M. oleifera* isothiocyanates are illustrated in [Figure 2](#). The flowers of *M. oleifera* contain high amounts of flavonoid pigments, including isoquercitrin, kaempferitrin, rhamnetin, quercetin, and kaempferol ([Fahey et al., 2001](#); [Bennett et al., 2003](#)).

[Foidl et al. \(2001\)](#) and [Pandey et al. \(2012\)](#) found that the leaf extracts of *M. oleifera* in 80% ethanol contain cytokine-like hormones. In an experiment conducted by [Al-Asmari et al. \(2015\)](#), it was demonstrated that such extracts possess cancer-preventive properties, as measured by the differentiation activity against human myeloid leukemia (HL-60) cells. [Grubben and Denton \(2004\)](#)

**Figure 2.** The chemical structures of moringa isothiocyanates.

discovered the presence of moringinine and moringine, which are alkaloids with medicinal properties, in the root bark of *M. oleifera*.

## Antioxidants in *M. oleifera* Leaves

Yameogo et al. (2011) reported that *M. oleifera* is the ultimate source of various natural antioxidants, including flavonoids such as quercetin and kaempferol. According to Siddhuraju and Becker (2003), *M. oleifera* solvent extracts from different agroclimatic regions have distinct antioxidant profiles. The dry weights of ascorbate (vitamin C), phenolics,  $\alpha$ -tocopherol, and  $\beta$ -carotene are 70 to 100 mol/g, 74 to 210 mol/g, 0.7 to 1.1  $\mu$ mol/g, and 1.1 to 2.8 mol/g, respectively. The leaves have much higher antioxidant levels than the fruits and vegetables. For example, strawberries have 190 mol/g of gallic acid (GA)/g and carrots have 1.8 mol/g of  $\beta$ -carotene. Soybeans have 1.8 mol/g of  $\alpha$ -tocopherol and hot peppers have 110 mol/g of ascorbate (Abbas and Ahmed, 2012).

The leaves of *M. oleifera* contain essential flavonoids, such as quercetin and kaempferol, which are stronger antioxidants than vitamin C (Anwar and Bhangar, 2003; Siddhuraju and Becker, 2003). *M. oleifera* leaves also possess a significant amount of ascorbic acid (Siddhuraju and Becker, 2003). According to Verma et al. (2009) and Sreelatha and Padma (2009), these antioxidants protect animals from degenerative illnesses and infections through the significant binding of free radicals, thus preventing oxidative DNA damage.

## Antimicrobial Activity of *M. oleifera* Leaf Meal

Infectious diseases are currently one of the main global public health concerns. Bacteria, fungi, parasites, and viruses, are the causative agents of infectious diseases in humans and animals (El-Saadony et al., 2021; Yaqoob et al., 2021; Abd El-Hack et al., 2022c; El-Saadony et al., 2022c) therefore, scientists and researchers focus on exploring alternative methods for combating antibiotic resistance in pathogenic microorganisms. This purpose can be achieved by adding plant extracts and some effective and safe natural substances to foods (El-Saadony et al., 2020, 2022a,b; Abd El-Hack et al., 2021a,b,c; Saad et al., 2021a,b).

Various parts of *M. oleifera* possess antimicrobial potentials, which are useful in the eradication of pathogenic microorganisms, biofilm menace, and water purification. The safety of *M. oleifera* usage has been demonstrated by its long-term use and ethnopharmacological properties. *M. oleifera* has not only been used for its antimicrobial activity but also for bioenhancement and as nanoparticles in drug delivery (Arora et al., 2013). At present, there is concern regarding the safety of water disinfectants as most of them are implicated in health-related anomalies (Righi et al., 2012). Several studies have reported that *M. oleifera* seed kernels possess water purifying properties. Eilert et al. (1981)

discovered a compound, 4- $\alpha$ -rhamnosyloxybenzyl isothiocyanate, presently known as glucosidal mustard oil, and found that it coagulates solid matter into water and eliminates most of the suspended bacteria.

Madsen et al. (1987) revealed that crushed *M. oleifera* seed kernels release natural polyelectrolytes, which function as flocculating agents by binding to suspended particles in a colloidal suspension. These bound particles form large sedimenting particles, known as flocs, and microorganisms attach to these flocs. Madsen et al. (1987) suggested that treating water with *M. oleifera* seed kernels (press cake) removes 90 to 99% of the fecal coliform bacterial load. However, they noted that after several hours of storage, the residual bacteria re-grew within the storage container and an additional disinfection process was required.

In similar studies, the flocculants obtained from *M. oleifera* seeds were further characterized as basic polypeptides with molecular weights of 6 to 16 kDa, with an isoelectric pH of 10 to 11 (Jahn, 1988). In a study based on traditional water purification using *M. oleifera* seeds, another group of researchers discovered a steroidal glycoside, strophantidin, as a bioactive agent that was highly efficient in the clarification and sedimentation of inorganic and organic matter in raw water. It reduced up to 65% of the microbial load after 24 h compared with an 83% reduction by alum under similar conditions (Olayemi and Alabi, 1994).

The potential of the active ingredients in *M. oleifera* seeds has been explored. Mangale et al. (2012) demonstrated that the number of bacterial and fungal colonies on plates decreased with increasing concentrations of the extract. Other studies revealed the inhibitory effects of various *M. oleifera* seed extracts on *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella typhi*, *Vibrio cholera*, *Aspergillus niger*, and *Candida albicans* (Atieno et al., 2011). The antibiotic agent in *M. oleifera* seeds has been identified as pterygospermin (Aney et al., 2009). It is believed that these extracts have a synergistic potential to restore the effectiveness of  $\beta$ -lactam antibiotics against methicillin-resistant *S. aureus* (Karthy et al., 2009).

Numerous studies have demonstrated the antimicrobial potential of *M. oleifera* leaves. For instance, a study on leaf extracts prepared in different solvents revealed that ether extract of *M. oleifera* leaves was the most effective component against the clinical and environmental isolates of *Proteus mirabilis*, a well-known causative agent of urinary tract infections (Arun and Rao, 2011). Several studies have been documented on the antibacterial activity of *M. oleifera* leaves against some bacterial species (Abalaka et al., 2011). Chuang et al. (2007) reported that the crude extracts and essential oils from *M. oleifera* leaves exhibit antifungal activity against *Trichophyton rubrum*, *T. mentagrophytes*, *Epidermophyton floccosum*, and *Microsporum canis*.

Patel et al. (2014) observed that both ethanolic and aqueous extracts of *M. oleifera* leaves were active against *Saccharomyces cerevisiae* and *Candida tropicalis* but not against *C. albicans*. Limited research is

available on the antimicrobial activity of *M. oleifera* roots because of conservation-related concerns of this important plant. However, a few studies have shown the antimicrobial potential of the roots of this plant. For instance, *in vitro* studies on different extracts of the root bark of *M. oleifera* against *S. aureus*, *E. coli*, *Salmonella gallinarum*, *P. aeruginosa*, and others showed that ethyl acetate and acetone extracts exhibit maximum activity compared with other solvents (Anitha et al., 2011). Similarly, limited research has been conducted on the antimicrobial potential of the stem bark of *M. oleifera*, except a few preliminary reports. Studies on the antimicrobial activity of root extract of *M. oleifera* against some human pathogens have demonstrated the presence of active organic extracts with varying levels of activity (Bolin and Satyabrat, 2011).

Bioenhancers are molecules that do not exhibit any drug activity of their own but promote and augment the biological activity, bioavailability, or uptake of drugs in combination therapy, resulting in reduced drug-associated toxicity, cost, and duration of chemotherapy. The first bioenhancing property of *M. oleifera* pod extract was reported by Khanuja et al. (2005), where a niaziridin-rich fraction enhanced the bioactivity of commonly used antibiotics, such as rifampicin, tetracycline, and ampicillin, against gram-positive and gram-negative bacteria. It also facilitated the absorption of drugs, vitamins, and nutrients through the gastrointestinal membrane, which increased their bioavailability (Khanuja et al., 2005).

This observation was corroborated by a recent pre-clinical study on the influence of *M. oleifera* pods on the pharmacokinetic disposition of rifampicin using high-performance liquid chromatography–photodiode array. The active fraction isolated from air dried pods of the plant mixed with rifampicin and administered to the experimental animals enhanced systemic availability of the drug and suppressed the drug metabolizing cytochrome P-450 (Pal et al., 2010). Few reports are available on the antimicrobial activity of *M. oleifera* pods. Sayeed et al. (2012) studied the *in vitro* antimicrobial activity of methanolic extracts of *M. oleifera* fruits and reported that it was effective against some bacteria and fungi. Similar to roots and pods, the antimicrobial potential of the seed coat has not been sufficiently studied.

Alikwe et al. (2013) conducted a preliminary study on the antibacterial activity of the ethanolic leaf extracts of *M. oleifera* against *P. aeruginosa*, *E. coli*, *Klebsiella* sp., *Salmonella typhimurium*, and *Proteus mirabilis*. This plant part has shown antibiofilm potential against *Staphylococcus epidermis* as reported by Dayal et al. (2013). The increasing failure of conventional antibiotics because of side effects and the emergence of resistant microorganisms drive the search for better alternatives. Plants have proven to be a useful source of potential bioactive molecules; however, only a small percentage of these potential candidates have been explored. For instance, based on the scientifically supported ethnopharmacological claims, *M. oleifera* possesses antimicrobial potential.

Most of the antimicrobial studies are preliminary; therefore, further studies to authenticate its candidature might be relevant. As recommended by Rios and Recio (2005), substantial knowledge could be obtained by the identification of the active fraction of extracts, mechanisms of action, and pharmacokinetic profile of extracts.

The presence of alkaloids, flavonoids (quercetin and kaempferol), saponins, and tannins in all extracts have been linked to various physiological actions in the human and animal bodies (Abdulkadir et al., 2015). Flavonoids have a hydroxyl group that confers antioxidant activity on *M. oleifera* and is thus used as a therapeutic agent (Pace-Asciak et al., 1995). Over the years, *M. oleifera* has been used as a traditional remedy for some diseases. It is rich in phytochemicals that exhibit effective antibacterial, antimycotic, antiviral, and potential anticancer activities. For instance, *M. oleifera* leaf extracts showed antiviral activity against foot and mouth disease (Younus et al., 2015). The antimicrobial properties of *M. oleifera* leaf extracts have also been reported against both gram-positive and gram-negative bacteria, such as *S. aureus*, *E. coli* and *Salmonella* (Van Weyenberg and Jacobs, 2013; Abdulkadir et al., 2015).

The antifungal properties of *M. oleifera* leaves have also been explored (Donli and Dauda, 2003). The extraction modes of the active ingredients play a role in the effectiveness of *M. oleifera* extracts against various pathogenic microorganisms. For instance, the antibacterial activity of the methanolic extracts of *M. oleifera* showed broader antimicrobial action compared with aqueous extracts (Donli and Dauda, 2003). *M. oleifera* has been known to exhibit both anti-inflammatory and anticancer properties (Cárceles et al., 1993; Bharali et al., 2003). Dried fruit powder possesses ameliorative potential against industrial fluorosis in cattle because altered hemato-biochemical parameters were restored after supplementation in fluorotic cows (Jena et al., 2016).

## Antinutritional Factors in *M. oleifera* Leaves

*M. oleifera* leaves contain low amounts of polyphenols, such as tannins (1.4%) and total phenols (2.7%), which are less harmful to animals if consumed in appropriate amounts (Makkar and Becker, 1997). However, when consumed in large amounts, these factors may negatively affect the ability of an animal to utilize dietary nutrients and consequently deteriorate their health. The *M. oleifera* leaf meal also contains 5.6% of the saccharides raffinose and stachyose, which produce flatulence in monogastrics when consumed in excessive amounts (Gupta et al., 1989). Additionally, it contains nitrates (0.5 Mmol/100 g), oxalates (4.1%), saponins (1.2%), and phytates (3.1%). The high phytate concentrations in the leaves decrease the bioavailability of minerals in monogastrics (Reddy et al., 1982). Saponins from some plants induce an adverse effect on the growth of animals but those present in *M. oleifera* leaves are safe and do

not exhibit hemolytic activity; therefore, humans can consume them without any adverse effects (Makkar and Becker, 1997).

### Potential Toxicity of *M. oleifera*

To the best of our knowledge, only a few studies have established the highly adverse effects of *M. oleifera* as food or medication in humans. According to Berger et al. (1984), in a study to investigate the potential toxicity of seeds from *M. stenopetala* and *M. oleifera*, no harmful effects were noticed during the study evaluation period and no modifications were found in the histologic pictures of 28 organs in outbred Sprague–Dawley rats (Berger et al., 1984).

In a safety assessment analysis, Adedapo et al. (2009) revealed that administering *M. oleifera* leaf extract to rodents for 3 wk at a maximum dosage of 2,000 mg/kg was safe. They also reported that a dosage of 400 mg/kg resulted in a substantial increase in the packed cell volume, whereas a dosage of 800 mg/kg resulted in a significant decrease in the hemoglobin level and red blood cell counts. Asare et al. (2012) also presented comparable results, confirming that ingestion is safe at a dosage of <1,000 mg/kg body weight. However, 4-hydroxyphenylacetonitrile, 4-hydroxyphenylacetamide, and phenyl acetonitrile are biosynthetically and chemically similar substances extracted from roasted *M. oleifera* seeds, which may be highly poisonous (Villasenor et al., 1989).

According to Bhattacharya et al. (1978), *M. oleifera* bark extracts can induce abortion and cause violent uterine contractions, which may lead to death. Kavitha et al. (2012) revealed that *M. oleifera* seed powder dramatically affects the biochemical and hematological parameters of aquatic organisms, which can be fatal to these organisms. Fahey (2005) stated that the presence of isothiocyanate producing glycosides might explain the varied effects of *M. oleifera* extracts on the hematological parameters. Das and Mukherjee (2000) showed that the consumption of *M. oleifera* decreased the blood protein levels and they demonstrated that glycoside cyanides and isothiocyanate may trigger stress-mediated protein mobilization. Furthermore, Becker and Makkar (1999) demonstrated that dietary tannic acid, a tannin found in *M. oleifera*, might negatively influence the growth performance of carps (*Cyprinus carpio* L.) after 28 d of treatment. Therefore, future research should focus on the potential negative effects of using *M. oleifera* products in fish diets.

### General Uses of *M. oleifera*

*M. oleifera* is a valuable plant as most of its parts are edible. The leaves of this plant can be used as food or forage during the wet and dry season (FAO, 2014). Humans consume *M. oleifera* pods, blossoms, roots, and leaves as a green vegetable substitute throughout Asia and Africa (Pandey et al., 2012). The consumption of leaves is suitable for vegetarians, especially for pregnant

and nursing mothers as well as children, because they contain a high percentage of protein, vital minerals, and vitamins (A, B, and C) (FAO, 2014). *M. oleifera* seeds can be consumed in the raw or cooked form. These seeds contain 30 to 40% edible oil (ben oil) (Pandey et al., 2012).

The high concentration of sterols, oleic acid, and tocopherols helps prevent rancidity (FAO, 2014). It possesses several medicinal properties, as shown in Figure 3. It has several therapeutic benefits, which include anti-inflammatory, anti-asthma, heart-protective, antioxidant, antiviral, and anticancer activities. *M. oleifera* seeds are rich in terygospermin with fungicidal properties as well as antibiotic properties against *P. aeruginosa*, *Bacillus subtilis*, *S. aureus*, and *Fusarium solani* (Price, 2007; Jabeen et al., 2008).

*M. oleifera* leaves, which are rich in iron, can cure anemic individuals. Humans also use the bark and roots of this plant to treat heart diseases (Orwa et al., 2009). According to Ogbe and John (2012), feeding *M. oleifera* leaves with other concentrates might boost the efficiency of the concentrate. Similarly, Price (2007) determined that soybean meal provided with *M. oleifera* leaves had a significant impact on poultry growth performance, with improved bird feed conversion ratio. *M. oleifera* seeds can be used in water purification and biodiesel generation (Orwa et al., 2009). According to Aruna and Sri-latha (2012), *M. oleifera* seed powder has antimicrobial properties that can disinfect and purify water in aquaculture ponds. Additionally, Egbuikwem and Sangodoyin (2013) determined the optimal amount of *M. oleifera* seed extract that was effective against *E. coli* in stream water; moreover, they found that the seed extract had a contaminant extraction efficiency of >90% for stream, well, and pond water specimens.

Rashid et al. (2008) reported that *M. oleifera* seeds have excellent properties necessary for biodiesel production. The oil cakes contain 1% flocculant proteins, which preserve the minerals and organic compounds during the purification of drinking water, making them suitable for water treatment. Further, they can be used for efficient fiber deposition in the beer and juice industries. Although *M. oleifera* seeds are not as efficient as alum in removing turbidity, they have been suggested as a potential alternative to some traditional chemically manufactured coagulants, such as alum, which may increase the risk of cancer. This is because these seeds are natural, ecofriendly, biodegradable, and safe (Preston et al., 2010; Aruna and Sri-latha, 2012; Egbuikwem and Sangodoyin, 2013).

According to Foidl et al. (2001) and Pandey et al. (2012), the oil obtained from *M. oleifera* seeds preserves aroma easily and can be used in the perfume industry. It is also less prone to rancidity, thus making it superior to other oils. The bark of *M. oleifera* can be used for dyeing; however, the wood is not suitable for use in heavy construction (Pandey et al., 2012). Sprinkling *M. oleifera* leaf extract on the leaves of peanut, sugarcane, soybean, and coffee improved the plant yield by 20 to 35% (Foidl et al., 2001). Owing to its antiviral effect, *M.*

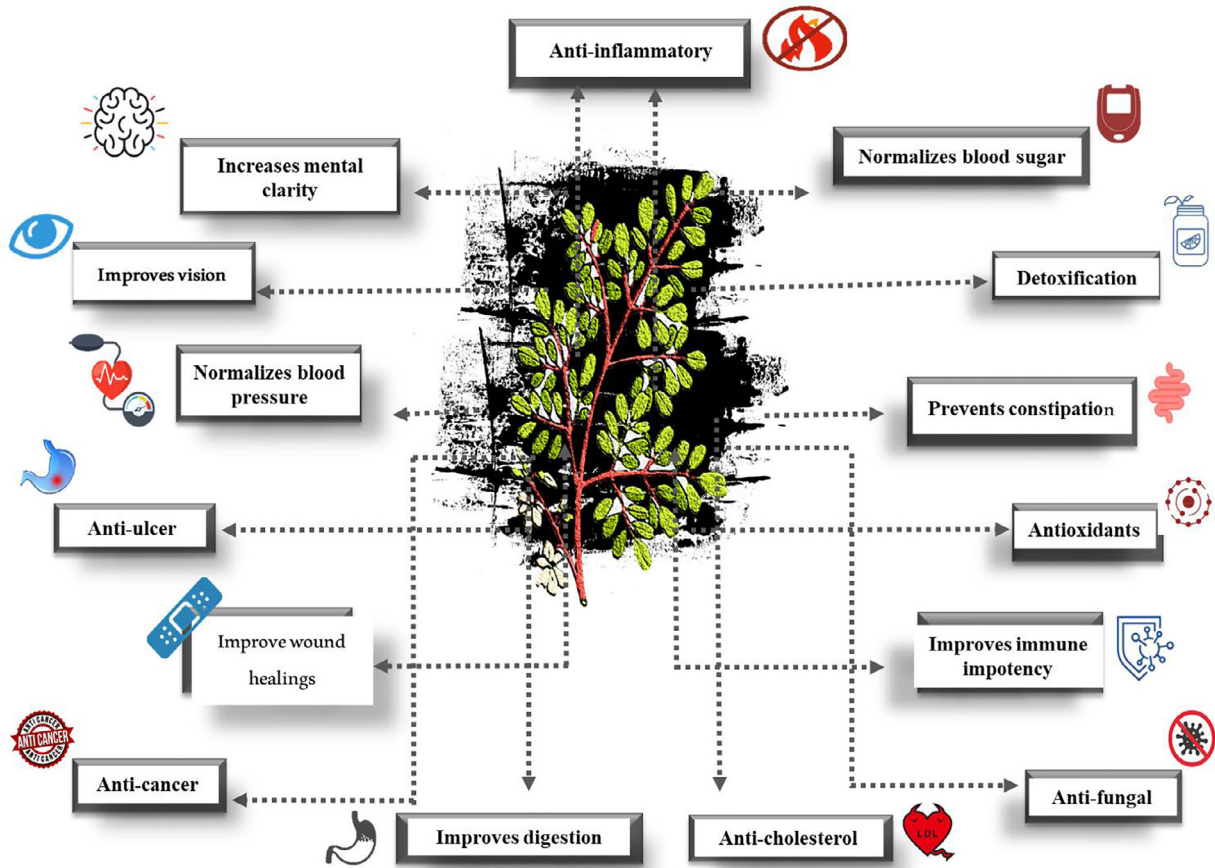


Figure 3. Medicinal properties of *Moringa oleifera* tree.

*oleifera* leaf extract can treat some viral diseases, especially the Newcastle disease virus (Chollom et al., 2012).

### *M. oleifera* Leaf Inclusion in Poultry Diets

The nutritional properties of *M. oleifera* leaf meal are summarized in Table 3. The leaves of *M. oleifera* are free of heavy metals, such as mercury, cadmium, and arsenic. They also have adequate amounts of vitamins, particularly A, B, and C; thus, including *M. oleifera* leaves in chicken diets is safe and can improve output performance in poultry production (Donkor et al., 2013). However, feeding *M. oleifera* leaves or leaf powder to poultry may have poor palatability (Price, 2007). Figure 4 highlights the effects of including *M. oleifera* leaves in poultry diets.

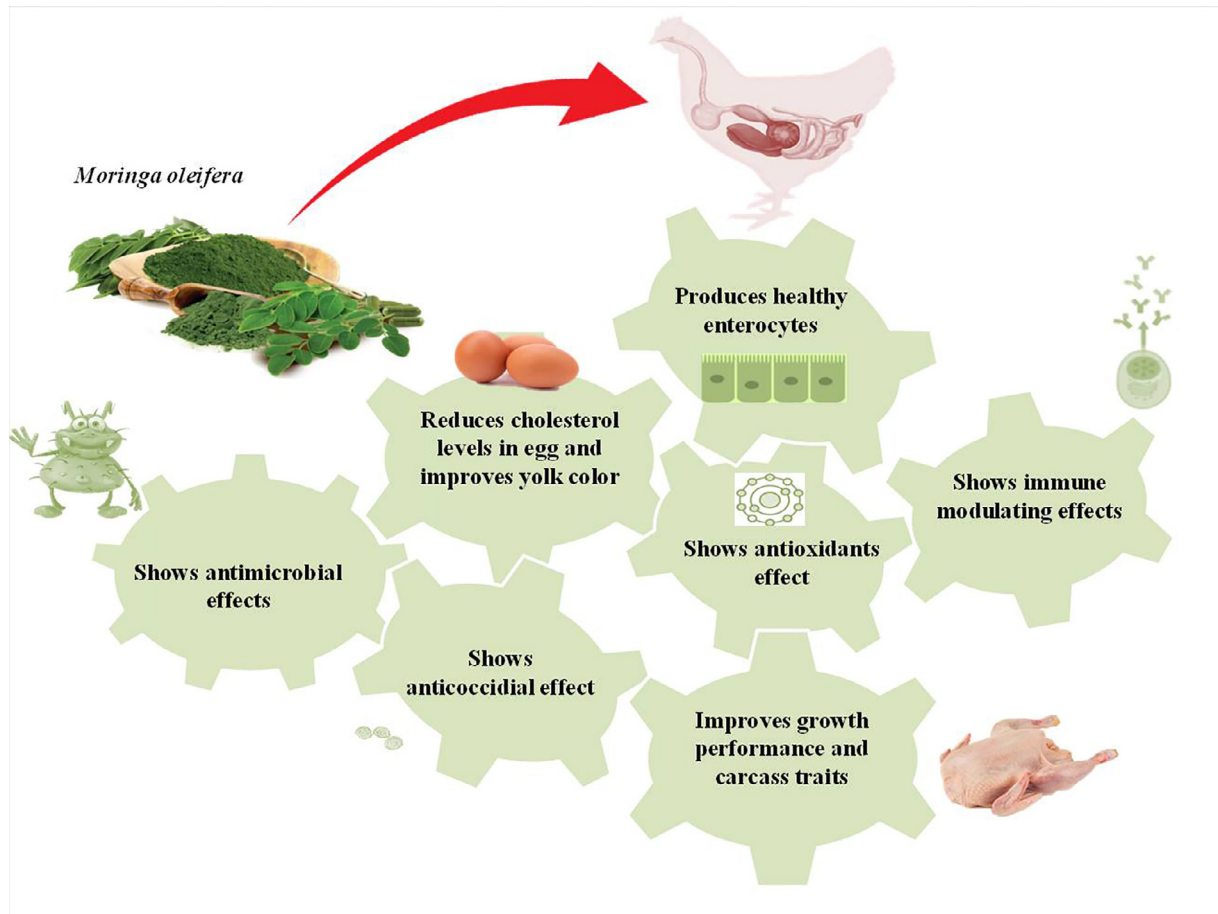
Several enzymes, including phytase, may be introduced to a diet containing *M. oleifera* leaves (Gaia, 2005; Fuglie, 2009). A sufficient amount of dietary *M. oleifera* leaves may positively influence the growth, carcass traits, and production performance of poultry. Ayssiwede et al. (2011) suggested that digestibility and antibacterial capabilities against gastrointestinal pathogens contribute to improved feed efficiency. *M. oleifera* forage can be safely added up to 10% to a cassava-based diet without lowering feed consumption. According to Ohugbemi et al. (2010), *M. oleifera* has hypocholesterolemic properties and can be added to chicken rations to significantly

reduce the cholesterol levels in eggs. Abou-Elezz et al. (2011) showed that *M. oleifera* leaf meals (approximately 10%) might improve yolk color without significant negative impacts on the egg-laying rate. According to previous research, 10% *M. oleifera* leaf meal is recommended as a long-term feed additive for layer diets. Compared with

Table 3. The nutritional qualities of *Moringa oleifera* leaves' meal.

Nutritive value	Dry leaves	References
Crude protein (CP %)	25.1 to 30.29	Moyo et al., 2011; Foidl et al., 2001
Neutral detergent fibers (NDF%)	11.40 to 21.9	Foidl et al., 2001; Richter et al., 2003; Moyo et al., 2011
Acid detergent fibers (ADF%)	8.49 to 11.4	Foidl et al., 2001; Richter et al., 2003; Moyo et al., 2011
Gross energy (MJ/kg DM)	18.7	Foidl et al., 2001
Ether extract (EE%)	5.4	Foidl et al., 2001
Lysine (Lys%)	1.1 to 1.64	Richter et al., 2003; Moyo et al., 2011
Histidine (His%)	0.6 to 0.72	Richter et al., 2003; Moyo et al., 2011
Threonine (Thr%)	0.8 to 1.36	Richter et al., 2003; Moyo et al., 2011
Arginine (Arg%)	1.2 to 1.78	Richter et al., 2003; Moyo et al., 2011
Methionine (Met%)	0.30	Moyo et al., 2011
Total phenolics (%)	2.02 to 2.74	Richter et al., 2003; Moyo et al., 2011
Tannins (%)	0.53	Richter et al., 2003
Condensed tannins (mg/g)	3.12	Moyo et al., 2011





**Figure 4.** The impacts of applying *Moringa oleifera* leaves in poultry diets.

the control, food supplementation with 2.5% *M. oleifera* leaf meal improved the quality of the internal eggs, as determined by Ebenebe et al. (2013).

The incorporation of different amounts of *M. oleifera* leaf meal (0, 5, 10, and 15%) to the layer diet resulted in lower egg production and egg-laying rate. In contrast, egg weight continued to increase quadratically with increasing doses of *M. oleifera* leaf meal (Olugbemi et al., 2010). Overall, 5% *M. oleifera* leaf meals were helpful to birds. However, 15 and 20% leaf meals showed negative effects according to Kakengi et al. (2007) and Abou-Elezz et al. (2011).

Other researchers reported that a high dose of *M. oleifera* can reduce the egg-laying rate. Replacing sunflower seed powder with 20% *M. oleifera* leaf powder in the layer diet significantly reduced the egg yield and total egg weight (Kakengi et al., 2007). Likewise, Mutayoba et al. (2003) stated that 20% *M. oleifera* leaf meal intake affected the production of large eggs and egg-laying rate even with food consumed. In contrast, a consumption rate of 5% supplementation had no negative impact. Etalem et al. (2013) claimed that *M. oleifera* leaf meal could replace soybean meal in broiler chicken rations, but the increased levels of dietary leaf meal decreased the growth rate in those chickens. The negative effect of high dose of leaf meal on nutrition may be due to inadequate protein digestion (Olugbemi et al., 2010).

Kakengi et al. (2007) reported that a significant amount of DM and forage intake was observed when laying hens were fed a diet supplemented with 10% and 20% *M. oleifera* leaf meals. This result was consistent with that of a previous study by Abou-Elezz et al. (2011), which revealed that the consumption of DM showed a squared trend with higher levels of *M. oleifera* leaf powder (0–15%). In contrast, high levels of *M. oleifera* leaf powder reduced the chicken feed system intake (Kakengi et al., 2007). When a small amount of *M. oleifera* leaf meal was added to the feed, there were no negative impacts on feed utilization, and it may enhance the feed conversion rate. Approximately 10% dietary addition of *M. oleifera* leaf meal did not affect feed consumption, feed conversion efficiency, or body weight (Junior et al., 2010). Broilers fed a diet supplemented with 5% *M. oleifera* leaf meal for 7 wk gained more weight, consumed more total feed, and converted feed more efficiently (Safa and Tazi, 2014). *M. oleifera* leaf meal can substitute groundnut cake in the grower rabbit diets, with an additional rate of up to 60% (Adeniji and Lawal, 2012).

In another study, Gadzirayi et al. (2012) stated that when *M. oleifera* leaf meal was included in the diet, the DM intake increased in broilers due to the increased bulk and metabolizable concentrations. *M. oleifera* leaf meal is a good source of yolk pigments and had no detrimental impacts on shell thickness or egg shape index

(Kaijage et al., 2003). This may be due to the high carotene levels in *M. oleifera* leaf meal, which extended from 15.25 to 16.30 mg/100 g (Etalem et al., 2013). More egg albumens and less yolk index indicate decreased cholesterol levels, which is a positive trait among egg consumers (Kaijage et al., 2003).

Low levels of *M. oleifera* supplementation enhanced egg quality, whereas excessive levels resulted in lower output of eggs (Abou-Elezz et al., 2011). The combination of 5% sunflower seed meal and *M. oleifera* leaf meal in the diet had a significant impact on the egg weight (Kakengi et al., 2007). The lower egg mass at high concentrations of *M. oleifera* leaf meal was probably because of decreased energy requirement, protein preservation, and CF nutritional value, as determined using 10% *M. oleifera* leaf meal (Lu et al., 2016). *M. oleifera* showed hypocholesterolemic characteristics, indicating that it lowers the cholesterol content of eggs in layer diets (Olugbemi et al., 2010). *M. oleifera* is widely known for its antioxidant properties, high phytochemical content, consumer acceptability, manufacturing properties, poultry product stability, and storage life (Jung et al., 2010; Abbas and Ahmed, 2012). The most essential antioxidant in *M. oleifera* is flavonoids, particularly flavonols (Pandey et al., 2012). They have a higher antioxidant capacity than vitamin C and can extend the life span of chicken products (Pennington and Fisher, 2009). These findings indicated that *M. oleifera* leaves are an excellent addition to the chicken diet; however, dietary amounts should be carefully monitored. Employing biosecurity measures, hygienic disposal of poultry waste along with a proper vaccination program, and the usage of natural feed additives can enhance poultry production worldwide and help to avoid the risk of infection with different avian pathogens (Abd El-Hack et al., 2022d; Attia et al., 2022; El-Naggar et al., 2022; Mahmoud et al., 2022).

### ***M. oleifera* as a Nonruminant Feed**

*M. oleifera* has extensive potential as a livestock feed (Richter et al., 2003). The low levels of antinutritional factors and high levels of protein, lipid, and sulfur-containing amino acids make it an excellent source of protein for nonruminants (Richter et al., 2003; Ferreira et al., 2008). *M. oleifera* leaves also contain all essential amino acids, including sulfur-containing amino acids, in higher concentration than the recommended daily intake, making it a good source of protein for monogastrics (Ferreira et al., 2008).

In Ghana, improved weight gains were reported in rabbits fed with *M. oleifera*; therefore, it was recommended for use either as partial or total replacement for soybean meal without any adverse effects on the productive performance and blood indices of weaned rabbits (Nuhu, 2010). In broilers, it was established that *M. oleifera* can replace soybean at 25% of the total diet without negatively affecting growth performance, feed intake, and feed conversion efficiency (Gadzirayi et al., 2012).

### **Other Uses of *M. oleifera***

*M. oleifera* seeds contain naturally occurring proteins that are more effective coagulants than alum (Ndabigengesere et al., 1995). Furthermore, *M. oleifera* seed extracts significantly improved water quality, particularly the number of cryptosporidium oocysts and water turbidity (Petersen et al., 2016). The relative lack of toxic compounds in the seed and its ability to clarify and purify muddy water make it a suitable alternative to obtaining clean drinking water (Ndabigengesere et al., 1995; Anwar et al., 2007; Ferreira et al., 2008). *M. oleifera* seed oil has high oxidative stability, making it fit for the cosmetic manufacturing (Sánchez-Machado et al., 2015). Alternatively, the pods can be used as litter in poultry and other housed livestock. These uses ensure the sustainable utilization of natural resources and environmental conservation.

## **CONCLUSIONS**

The valuable *M. oleifera* tree, also called the “drumstick” or horseradish tree, can be grown in severe dry and cold conditions. It has a wide range of nutrients. *M. oleifera* contains crude protein ranging from 71.2 to 391.7 g/kg in different parts of the plant. In previous studies, *M. oleifera* leaf meal has partially replaced sunflower seed cake and soybean meal as a protein source in chicken rations. Leaf meal has been associated with significant economic benefits, no adverse side effects, and even improved growth and product quality at appropriate dietary integration levels (5–10% in broiler rations and 10% in layer rations). Nevertheless, *M. oleifera* leaf meal (20% for broilers or layers and 80% for rabbits) may have specific harmful effects, possibly because of high levels of unique substances, such as tannins, which influence feed absorption or nutrient digestibility. The components and nutrients, including bioavailability and amino acid profile, of *M. oleifera* leaf meal must be studied in detail so that it can be frequently and widely used in poultry diets.

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## **DISCLOSURES**

The authors declare no conflict of interest.

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