Review Article

Moringa as a Natural Feed Supplement for Livestock: Impact on Growth Performance, Milk and Meat Production, Semen Quality and Hormonal Regulation

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Abstract | *Moringa oleifera*, a plant known for its high nutritional value and bioactive compounds, has emerged as a promising natural feed supplement in Livestock production. This review aims to evaluate the effects of *Moringa oleifera* as a natural feed supplement on Livestock by synthesizing findings related to growth performance, milk and meat production, semen quality, and hormonal regulation. The main themes include nutritional value, bioactive compounds, and their roles in enhancing productivity, reproductive function, and overall animal production. Its potential to improve growth performance, milk and meat production, semen quality, and hormone regulation has made it a focal point of research in sustainable agriculture. Rich in polyphenols, flavonoids, vitamins A, C, and E, essential amino acids, and minerals, moringa enhances feed efficiency and digestibility across various Livestock species. In ruminants, including cattle, sheep, and goats, moringa supplementation has been shown to improve growth rates, reproductive efficiency, and milk production, with increases in milk yield of up to 20%. The plant's high content of antioxidants, such as flavonoids and carotenoids, helps mitigate oxidative stress and enhances nutrient utilization, thus boosting productivity. In poultry, moringa enhances feed conversion ratios, carcass yield, liver function, and gut health, promoting overall growth and immunity. Its effects on meat quality in rabbits, broilers, and pigs are equally impressive, where it reduces lipid oxidation, improves tenderness, and stabilizes meat color. Additionally, moringa's antimicrobial properties help reduce microbial load, benefiting both animal health and meat safety. Moringa also demonstrates significant improvements in semen quality, with studies showing enhanced sperm motility, viability, and acrosomal integrity. It reduces oxidative damage in semen, improving fertility. Zinc in moringa further supports testosterone production, which enhances spermatogenesis and sperm mobility. The plant's influence on hormone regulation is particularly pronounced in males, where it increases testosterone and gonadotropins, enhancing male fertility and reproductive performance. Despite some variations in effects by species and dosage, *Moringa oleifera* stands out as a valuable, sustainable feed supplement that improves livestock productivity, reproductive health, and overall well-being.

Keywords | *Moringa oleifera*, Feed supplement, Livestock, Productive and reproductive performance

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INTRODUCTION

Nutrition plays a critical role in enhancing the health, productivity, and reproductive performance of Livestock species such as sheep, goats, cattle, and buffalo. These animals typically rely on grazing and forage as their primary sources, but the quality and availability of these resources can be limited, particularly in regions with harsh climates or poor pasture conditions. Inadequate supplementation can lead to nutritional deficiencies, resulting

in reduced growth rates, decreased milk production, and compromised reproductive health. Therefore, the key challenge is to provide balanced nutrition that fulfills the animals' energy, protein, and mineral requirements, while also managing the costs and availability of high-quality supplemental feeds. The need for alternative feed sources is growing, especially considering climate change, resource scarcity, and rising feed costs. Non-traditional feeds, such as food by-products, agro-industrial residues, and locally available plants, are emerging as sustainable options. These alternatives help reduce dependency on conventional feed crops, which in turn decreases the competition for land and resources used for human food production. Among these alternative feed sources, *Moringa oleifera* stands out as a highly nutritious plant with significant potential for Livestock feeding. Commonly known as the drumstick or horseradish tree, *Moringa oleifera* belongs to the *Moringaceae* family (Morton, 1991; Ramachandran *et al*., 1980). Native to the sub-Himalayan regions, it is well adapted to tropical and subtropical climates, with a widespread distribution across Africa, Saudi Arabia, Southeast Asia, the Caribbean Islands, and South America (Afolabi *et al*., 2013). Thriving in warm climates, it is extensively cultivated in countries such as Bangladesh, India, Pakistan, and Afghanistan (Mendieta-Araica *et al*., 2011; Sreelatha and Padma, 2009). In many tropical regions, Moringa is commonly grown in home gardens or used as a live fence due to its adaptability and rapid growth (Aminu *et al*., 2011). In addition to its agricultural importance, *Moringa oleifera* is widely recognized as a "miracle tree" due to its diverse therapeutic applications. Historically valued by ancient civilizations, including the Greeks, Romans, and Egyptians, moringa was used to treat a variety of conditions such as tumors, fever, epilepsy, inflammation, ulcers, hypertension, cholesterol issues, diabetes, liver disorders and animal infections (Mehta *et al*., 2011; Sharma *et al*., 2012; Huang *et al*., 2012; Ketpanyapong *et al*., 2023; Jatoi *et al*., 2024; Razooki *et al*., 2025). Recent studies into its bioactive compounds have further highlighted its global significance, with increasing recognition in Europe, North America, and Asia (JianFeng *et al*., 2012). Despite growing interest, there remains a lack of integrated research directly assessing the effects of *Moringa oleifera* supplementation on key Livestock performance indicators, particularly regarding its influence on growth, reproductive traits such as semen quality, and hormonal responses in ruminant species. Therefore, the objective of this review is to assess the potential of *Moringa oleifera* as a natural feed supplement for Livestock, focusing on its impact on growth performance, feed efficiency, meat and milk production, as well as its effects on semen quality and hormone regulation. Figure 1 provides an overview of the multifactorial effects of *Moringa oleifera* (powder leaf and leaf extract) supplementation in Livestock.

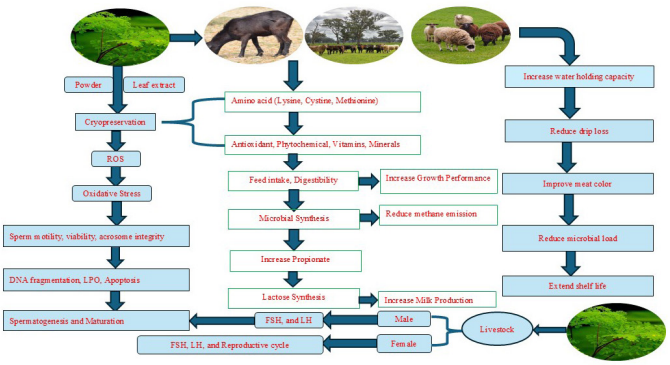

Figure 1: Overview of the multifactorial effects of *Moringa oleifera* (powder leaf, and leaf extract) supplementation in Livestock. Moringa influences growth performance, milk and meat production, semen quality, and hormonal regulation through its rich composition of amino acids, antioxidants, phytochemicals, vitamins, and minerals.

Bioactive Compounds and Phytochemicals in *Moringa oleifera*

Moringa oleifera is celebrated for its rich array of bioactive compounds and phytochemicals, which are central to its medicinal and therapeutic properties. These include antioxidants and nutraceuticals such as phenolic acids (catechin, epicatechin, ferulic acid, ellagic acid, myricetin), flavonoids, glycosides, carotenoids, alkaloids, glucosinolates, sterols, terpenoids, tannins, saponins, and fatty acids. These compounds play a key role in mitigating oxidative stress and promoting overall health (Sinha *et al*., 2012; Sreelatha and Padma, 2009; Stohs and Hartman, 2015; Leone *et al*., 2015b, 2016; Brilhante *et al*., 2017; Meghwal, 2017; Dhakad *et al*., 2019). The antioxidant properties of these bioactive compounds are especially important in reducing oxidative stress and preventing cellular damage (Kumar and Pari, 2003; Chumark *et al*., 2008; Sreelatha and Padma, 2011; Biswas *et al*., 2012).

Among the various parts of Moringa, the leaves are particularly rich in polyphenolic compounds and antioxidants, which significantly contribute to the plant's therapeutic effects. The leaves contain high levels of quercetin-3-glycoside, rutin, kaempferol glycosides, as well as other antioxidants like ascorbic acid, carotenoids, saponins, glycosides, and essential fatty acids. These compounds are particularly effective in scavenging reactive oxygen species (ROS), reducing oxidative stress and improving health outcomes (Agarwal *et al*., 2008; Bucak *et al*., 2010; Allai *et al*., 2016; D'Cruz and Mathur, 2005; Kamalakkannan and Prince, 2006; Al-Malki and El Rabey, 2015).

In addition, moringa leaves are exceptionally rich in essential vitamins and minerals—containing seven times more vitamin C than oranges, four times more vitamin A than carrots, and three times more iron than spinach—fur-

ther enhancing their antioxidant and nutritional benefits (Dhalaria *et al.*, 2020). Beyond the leaves, other parts of the moringa plant also contribute a variety of bioactive compounds, enriching the plant's overall nutritional and medicinal value. For example:

- Seeds contain compounds like cellotriose, moringin, flavonoids, and 2-decenal.
- Bark is rich in eugenol, palmitic acid, and dibutyl phthalate.
- Flowers and pulps provide tannins, saponins, and flavonoids.
- Roots contain moringin, sucrose, and glucotropaelin (Luqman *et al.*, 2012).

These bioactive compounds, along with essential vitamins (A, C, E) and proteins, contribute to the plant's diverse therapeutic potential, supporting immune function, reducing inflammation, and improving overall health. Moringa leaf meal (MOLM) and leaf extract (MOE) are particularly rich in antioxidants like ascorbic acid, flavonoids, and carotenoids, which further enhance the plant's free radical-scavenging ability (Anwar *et al.*, 2005; Abd Eldaim *et al.*, 2017). In addition to antioxidant activity, Moringa extracts also exhibit antibacterial, antifungal, anti-inflammatory, and antihypertensive effects, with demonstrated efficacy against both Gram-positive and Gram-negative bacteria (Sadek *et al.*, 2013; Sokunbi *et al.*, 2015; Peixoto *et al.*, 2011). Figure 2 summarizes the key bioactive compounds and phytochemicals found in various parts of *Moringa oleifera*. Through a comprehensive evaluation of Moringa's bioactive compounds and phytochemicals, it is evident that the plant holds immense potential as a natural resource for health promotion and disease prevention, showcasing its wide-ranging therapeutic benefits.

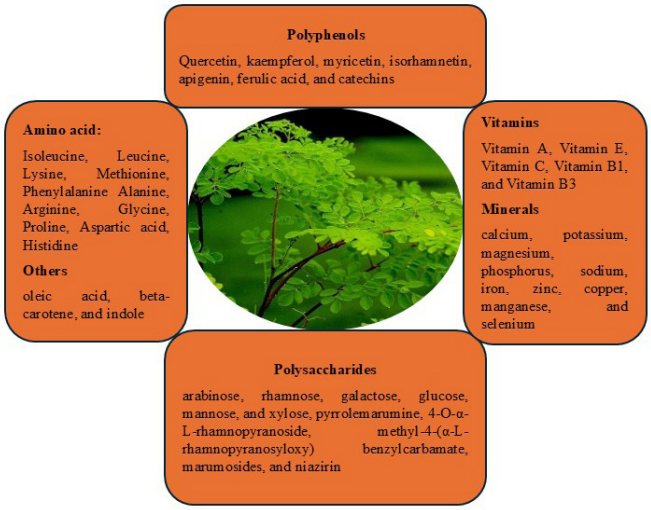

Figure 2: Bioactive compounds and phytochemicals.

Moringa oleifera as a Feed Supplement

The growing demand for Livestock products has increased pressure on conventional animal feed sources. As a result, alternative feedstuffs like *Moringa oleifera* have gained attention due to their nutritional value, palatability, and digestibility. Moringa leaves are rich in protein and minerals, making them an ideal supplement for various Livestock , including cattle, sheep, goats, pigs, and rabbits. The presence of alkaloids, polyphenols, and polysaccharides further enhances its value as a feed additive (Moyo *et al.*, 2012). *Moringa oleifera* has also been shown to reduce methane (CH_4) emissions from ruminants by inhibiting methanogenic microbes in the rumen. Studies indicate methane reductions of up to 17% in cows (Soliva *et al.*, 2005) and 50% in vitro (Elghandour *et al.*, 2017). The tannins and saponins in Moringa are believed to contribute to these effects (Dong *et al.*, 2019; Haque, 2018). Furthermore, Moringa improves ruminal nutrient utilization, enhancing feed efficiency, which adds to its value as a supplement for both reducing methane emissions and improving productivity. In tropical regions, Moringa offers additional benefits, such as resistance to drought and chill stress (Olusanya *et al.*, 2020).

Moringa supplementation has been shown to improve microbial protein synthesis in the rumen, resulting in enhanced Livestock performance (Nouman *et al.*, 2014). It also contains higher crude protein (CP) and lower neutral detergent fiber (NDF) than conventional feedstuffs, making it more palatable (Moyo *et al.*, 2012). Studies by Kholif *et al.* (2019) and Sultana *et al.* (2015) have demonstrated improved digestibility and nutrient content in goats fed Moringa. Moringa leaves can be fed fresh or dried and included in ruminant diets at levels of 20–50% without negative effects (Gumede *et al.*, 2022). Additionally, the polyphenols in Moringa may help enhance the immune system of animals (Al-Juhaimi *et al.*, 2020), while its high nutritional content makes it an effective supplement for protein-deficient diets, improving feed intake, digestion, and nutrient absorption (Masih *et al.*, 2019).

In poultry, *Moringa oleifera* has been shown to enhance appetite, increase carcass yield, stimulate digestive enzyme production, and provide immune-boosting and antibacterial effects (Selim *et al.*, 2021). Moreover, it has potential benefits for reproductive health and sperm quality in cattle (Jaja-Chimedza *et al.*, 2017) and ducks (Islam *et al.*, 2024). Several studies have also demonstrated the advantages of *Moringa oleifera* supplementation in various species. Sun *et al.* (2018) found that moringa leaves could effectively replace the alfalfa meal, improving growth performance, feed conversion ratio, meat quality, and antioxidant enzyme activity. Melesse *et al.* (2013) suggested that moringa leaves and pods could serve as alternative protein and energy supplements for tropical ruminants, particularly during dry periods. Khan *et al.* (2017) reported that 1.2% *Moringa oleifera* leaf powder in broiler diets promoted gut

health. Hadad *et al.* (2024) showed that moringa supplementation in rabbit diets modulated immune function and improved histological and physiological parameters of the intestine, liver, and spleen. Chen *et al.* (2020) concluded that Moringa extract (up to 10 g/kg) is safe for laying hens, enhancing performance and organ health without adverse effects. Abu Hafsa *et al.* (2020) also observed growth improvements in broilers fed up with 1% *Moringa oleifera* leaves. In conclusion, *Moringa oleifera* offers a promising alternative feed supplement with numerous nutritional, environmental, and health benefits. Its ability to improve Livestock productivity, reduce methane emissions, and enhance animal health makes it an invaluable resource for sustainable Livestock farming. Future research on *Moringa oleifera* as a feed supplement should optimize species-specific dosages, improve nutrient bioavailability, and clarify interactions with other feeds. Addressing antinutritional factors, nutrient variability, palatability, storage, standardization, and regulatory approval is essential for safe, effective use. Figure 3 illustrates the overall benefits of *Moringa oleifera* as a Livestock feed.

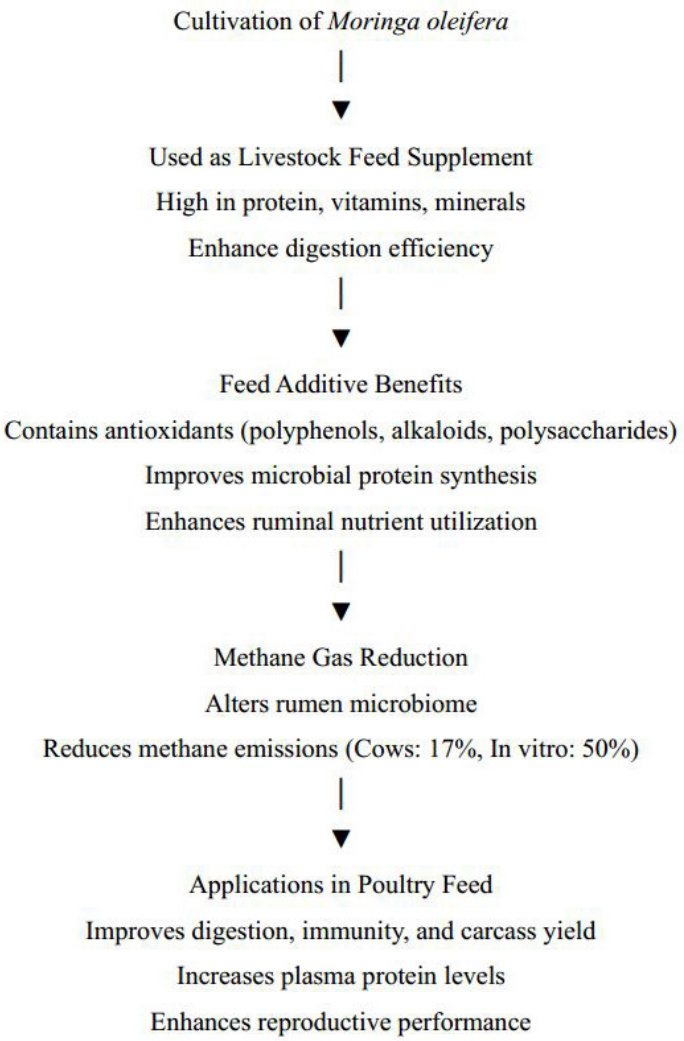

Figure 3: Overall benefits of *Moringa oleifera* as livestock feed.

Effect of Moringa on Growth Performance

Moringa oleifera leaf meal (MOLM) has demonstrated positive effects on growth performance across various animal species, primarily due to its rich composition of bioactive compounds such as methionine, lysine, scordinine, cystine, and antioxidants (Kusmardika, 2020; Desy *et al.*, 2021). In poultry, MOLM has been shown to enhance weight gain, feed consumption, feed conversion ratio (FCR), carcass characteristics, liver function, and intestinal health (Tutubalanga *et al.*, 2022; Mahfuz and Piao, 2019; Zhang *et al.*, 2023; Divya *et al.*, 2014). Broiler studies report that MOLM supplementation up to 25 g/kg does not impair nutrient utilization and may enhance growth (Nkukwana *et al.*, 2014). MOLM improved growth and carcass quality in indigenous chicken strains, particularly in Black Australorp chickens (Sebola *et al.*, 2015). In quail, supplementation with 0.25–0.50% MOLM improved growth (Talukdar *et al.*, 2020), while up to 24% MOLM had no negative effects in Senegal chickens (Ayssiwede *et al.*, 2011). In ducks, 4% MOLM improved body weight and FCR (Islam *et al.*, 2024). The form of supplementation also matters—aqueous MOLM extract outperformed antibiotics in improving FCR in broilers (Paul *et al.*, 2018), whereas 5% MOLM increased feed intake and FCR (El-Tazi *et al.*, 2014). However, some studies report no significant effects on poultry growth performance (Khan *et al.*, 2017; Khan *et al.*, 2021; Ashour *et al.*, 2020).

In rabbits, MOLM supplementation improved average daily gain (ADG), FCR, digestibility, antioxidant status, and cecal fermentation, supporting its use as a natural alternative to antibiotics (Bhatt *et al.*, 2023; Hashem *et al.*, 2019). In pigs, the effects of MOLM are more variable. While a 10% MOLM diet showed no improvement in ADG (Acda *et al.*, 2010), 4% Moringa leaf powder improved growth, carcass traits, and pork quality in finishing pigs by modulating muscle fiber types, enhancing protein and amino acid content, and increasing total unsaturated fatty acids (TUFAs) while reducing saturated fatty acids (TSFAs) (Chen *et al.*, 2021). However, diets with 60 g/kg Moringa seed meal (MSM) had no significant effect on growth or slaughter performance, while 100 g/kg increased the feed-to-gain ratio and serum ALT activity, and reduced serum glucose levels (Zhai *et al.*, 2020). A diet containing 20% Moringa leaf powder did not affect overall growth but limited body mass to 14%, impairing linear growth and raising concerns for undernourished animals or children (Zvinorova *et al.*, 2015). *Moringa oleifera* has demonstrated positive effects on growth performance across species. In poultry, up to 10% inclusion of seed meal improved performance, with Yoruba Ecotype Nigerian Local Chickens outperforming Isa Browns even at 15% (Akintunde and Toye, 2023). Broilers fed 1.5% leaf meal with multienzymes showed improved weight gain, FCR,

and carcass traits (Meel *et al.*, 2021), while higher levels in pullets improved FCR despite no changes in weight gain (Ugwuoke *et al.*, 2020). A 2.5% leaf powder inclusion is recommended for laying hens (Li *et al.*, 2023). In small ruminants, seed powder enhanced ewe weight gain despite reduced intake (Salih *et al.*, 2025), and 25% leaf meal improved lamb growth and carcass traits without adverse effects (Bhokre *et al.*, 2023). In rabbits, leaf meal inclusion up to 15% showed no negative impact on growth (Mankga *et al.*, 2022).

In ruminants, MOLM supplementation has consistently improved growth performance, feed intake, and nutrient digestibility. In lamb and kids, Moringa-based diets significantly increased ADG ($P \leq 0.01$). MOLM improved growth and nutrient utilization in sheep and goats (Murro *et al.*, 2003; Sultana *et al.*, 2017; Zaher *et al.*, 2020) and enhanced reproductive efficiency in Barki sheep (El-Hedainy *et al.*, 2020) and weight gain in Mehsana goats (Damor *et al.*, 2017). Moringa leaf-based diets also improved milk yield, composition, and antioxidant profiles in ewes and goats, thereby supporting offspring growth (Babiker *et al.*, 2017). In sheep, Moringa leaf meal (MLM) increased crude protein intake and digestibility compared to soybean meal (SBM) ($P = 0.024$) (Jelali and Salem, 2014). Moringa stenopetala leaf meal improved feed intake, weight gain, and carcass quality ($P < 0.01$) in poultry, especially at moderate inclusion levels (Melesse *et al.*, 2013). In dairy cows, replacing alfalfa hay with *M. oleifera* leaves and peduncles (10.85%) increased dry matter intake, nutrient digestibility, and rumen fermentation without negatively affecting ruminal pH (Li *et al.*, 2019). Similarly, in buffaloes, MOLM enhanced rumen fermentation, accelerated growth, and reduced methane emissions (Abdel-Raheem and Hassan, 2021). Supplementation with 4 g/day of defatted Moringa seed meal improved weight gain in ruminants without altering hay intake or digestibility (Ben Salem and Makkar, 2009).

Additionally, MOLM and its extracts have been shown to enhance total antioxidant capacity (TAC) and improve immune tolerance (Tuorkey, 2016). However, excessive MOLM intake can result in adverse effects (Zaher *et al.*, 2020). Overall, while MOLM generally enhances growth, feed efficiency, and animal health, its effects are dose-dependent and species-specific. Furthermore, research on *Moringa oleifera* and growth performance should focus on optimizing species- and breed-specific inclusion levels, comparing different forms (leaf meal, seed meal, extracts). Additionally, economic feasibility and cost-benefit analysis should be integrated to support practical application in commercial animal production. Figure 4 illustrates the underlying biological and nutritional mechanisms through which *Moringa oleifera* influences growth performance across animal species.

Figure 4: Mechanism of moringa on growth performance.

Effect of Moringa on Milk Production and Composition

Moringa oleifera, rich in antioxidants, essential amino acids, flavonoids, phenolics, selenium, and vitamins, has been shown to improve both milk yield and quality in lactating ruminants. Studies in goats and sheep have reported up to a 20% increase in milk production, along with enhanced protein and fat content (Kekana *et al.*, 2019). Kholif *et al.* (2015) found that incorporating 15% moringa leaf meal improved feed intake, nutrient digestibility, and milk yield in goats. Similarly, Afzal *et al.* (2022) observed improvements in antioxidant status, milk production, and reproductive health with 3.5% Moringa supplementation. In Nubian goats, Moringa supplementation increased milk yield by 6%, and Moringa seed cake (2.5%) improved both milk composition and fat-corrected milk yield in ewes (Aboamer *et al.*, 2020).

Moringa also positively influences milk fatty acid profiles by reducing saturated fats while increasing unsaturated fats and conjugated linoleic acid (CLA) levels (Kholif *et al.*, 2019). It enhances gluconeogenesis and lactose synthesis by increasing ruminal propionate levels (Rigout *et al.*, 2003; Kholif *et al.*, 2015). In dairy cows, Moringa supplementation has been shown to improve milk production, reproductive health, and immune function, particularly in arid environments (Cohen-Zinder *et al.*, 2016; Liu *et al.*, 2020).

Although some studies report no effect on milk yield (Olvera-Aguirre *et al.*, 2020; Dong *et al.*, 2019), others confirm Moringa's role in enhancing milk yield, composition, and overall animal health (Khalel *et al.*, 2014; Sarwatt *et al.*, 2004). Furthermore, Moringa improves protein and amino acid utilization, boosting productivity. Its antioxidants and antimicrobial properties contribute to enhanced milk production efficiency (Verma *et al.*, 2009; Shaani *et al.*, 2016).

Moringa oleifera silage has been shown to reduce dry matter (DM) and neutral detergent fiber (NDF) digestibility, increase serum urea concentrations, and decrease total cholesterol (TC), high-density lipoprotein cholesterol (HDLC), and low-density lipoprotein cholesterol (LDLC) levels—supporting its role as a partial substitute for alfalfa hay and maize silage in lactating cows (Zeng *et al*., 2018). Additionally, Moringa supplementation enhances colostrum protein levels, improving reproductive performance in sows and health outcomes in piglets (Sun *et al*., 2020). Moringa supplementation significantly increased milk fat, lactose, SNF, and total solids, reduced somatic cell count, and improved economic efficiency, without affecting milk yield or protein content in Lactating Rathi Cows (Saini *et al*., 2024).

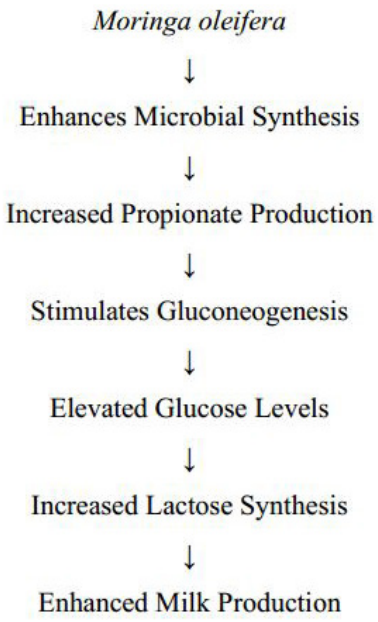

Figure 5: Impact of *Moringa oleifera* on milk production through microbial metabolism.

Moringa supplementation significantly increased ($P < 0.05$) daily DM intake (from 8.5 to 10.2 and 11.0 kg) and milk yield (from 3.1 to 4.9 and 5.1 kg). Although milk composition (fat, total solids, crude protein) and sensory attributes (taste, smell, color) remained unaffected, apparent digestibility of DM, organic matter (OM), crude protein (CP), NDF, and acid detergent fiber (ADF) improved significantly ($P < 0.05$). In conclusion, *Moringa oleifera* foliage enhances intake, digestibility, and milk production in cows fed low-quality forages, without altering milk quality (Sánchez *et al*., 2006). Research on *Moringa oleifera* and milk production should optimize dosage, form, and species-specific responses, while exploring bioactive effects on milk synthesis, composition, and rumen fermentation. Long-term studies should assess lactation, immunity, reproduction, fatty acid profiles, particularly increases in unsaturated fats and CLA, is essential for understanding human health implications, forage interactions, economic viability, and consumer acceptance for sustainable dairy use. Figure 5 illustrates the proposed mechanism by which *Moringa oleifera* enhances milk production through microbial metabolism and improved nutrient utilization in rumen.

Effect of Moringa on Meat Quality

Moringa oleifera (MOL) has shown potential in improving meat quality across various Livestock species, including rabbits, broilers, and pigs. In rabbits, a 10% inclusion of MOL (MOL10) resulted in reduced drip loss, increased moisture content, improved tenderness, and changes in meat color, with a decrease in redness (a* value) and an increase in yellowness (b* value), likely influenced by pH and myoglobin content (Castellini *et al*., 2002; Ayssiwede *et al*., 2011; Dougnon *et al*., 2012). In broilers, a 1.56% MOL inclusion enhanced meat quality without affecting growth performance (Cui *et al*., 2018), while a higher inclusion of 2.0% reduced microbial load and TBA values, suggesting benefits for liver function, gut health, and overall meat quality (Divya *et al*., 2014). The antimicrobial properties of MOL, attributed to its bioactive phytochemicals, help decrease harmful gut bacteria, such as Staphylococcus aureus and coliforms (Djakalia *et al*., 2011). MOL is also rich in antioxidants, which help mitigate lipid oxidation, enhancing meat shelf life and color stability (Tavarez *et al*., 2011). In pigs, MOL supplementation improved meat quality without adversely affecting feed conversion ratio or carcass characteristics (Mukumbo *et al*., 2014; Borah and Haloi, 2024). These effects are attributed to MOL's high content of carotenoids, vitamins, minerals, and bioactive compounds, which influence lipid oxidation and fatty acid composition (Verma *et al*., 2009; Sreelatha and Padma, 2009). Furthermore, MOL enhances water retention, reduces moisture loss during cooking, improves tenderness and texture, and lowers intramuscular fat content (Abdoun *et al*., 2024). Its antioxidant activity also helps stabilize meat color by preventing metmyoglobin formation (Falowo *et al*., 2014). In conclusion, MOL serves as a valuable natural feed additive for improving meat quality in Livestock production, benefiting both animal health and consumer satisfaction (Mancini and Hunt, 2005; Qwele *et al*., 2013). Future research on *Moringa oleifera* in meat production should optimize dosage and form by species, assess long-term effects on quality, shelf life, and sensory traits, and explore mechanisms affecting lipid oxidation, muscle composition, fatty acids and consumer acceptance. Figure 6 provides a schematic representation of how *Moringa oleifera* inclusion improves meat quality and shelf life through its antioxidant, antimicrobial, and bioactive nutrient effects.

Effect of Moringa on Semen Quality

Moringa oleifera (*M. oleifera*) has been shown to significantly improve semen quality in various species, enhancing

sperm motility, viability, acrosomal integrity, and plasma membrane integrity, while reducing lipid peroxidation. The most notable improvements are observed at specific concentrations, with Gangwar *et al.* (2024) and Allai *et al.* (2016) reporting enhanced semen quality, particularly in the 50 mg/100 ml TRIS group, where reduced ROS formation contributed to the improvement. These effects have been documented across multiple species, including bubaline (Doidar *et al.*, 2018; Iqbal *et al.*, 2022), bovine (Iqbal *et al.*, 2022), ovine (Shokry *et al.*, 2021), and boars (Ditama *et al.*, 2024), where moringa supplementation notably improved sperm motility and acrosomal membrane integrity. Moringa supplementation has also demonstrated protective effects against cryopreservation-induced oxidative stress in goats (Wahjuningsih *et al.*, 2019) and improved semen quality in frozen rams (El-Seadawy *et al.*, 2022), rabbits (Jimoh *et al.*, 2021), and cattle (El-Sheshtawy and El-Nattat, 2020a; 2020b). Zinc in moringa has been shown to stimulate testosterone production in Leydig cells, supporting spermatogenesis and sperm motility (Shokry *et al.*, 2021), while zinc and folate contribute to increased sperm concentration and improved fertility (Bindari *et al.*, 2013). In Bali bulls, moringa supplementation improved libido and semen quality (Anggara *et al.*, 2021).

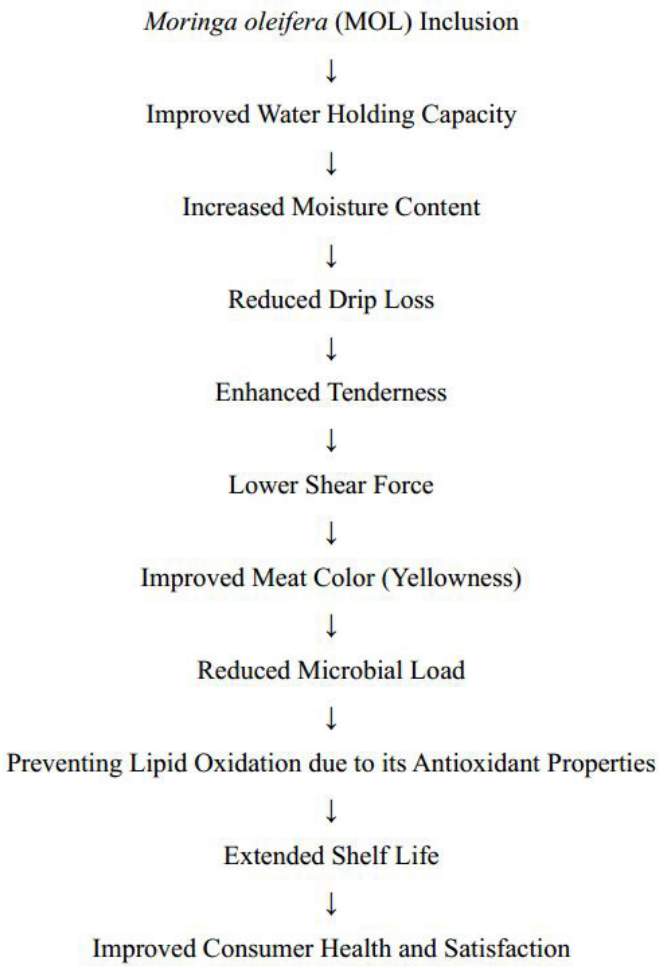

Figure 6: Effects of *Moringa oleifera* inclusion on meat quality and shelf life.

The antioxidant properties of moringa, including polyphenols, flavonoids, and vitamins C and E, help reduce ROS-induced lipid peroxidation, improving semen quality (Moyo *et al.*, 2012; Jayawardana *et al.*, 2015; Allai *et al.*, 2016). It also enhances fertility when used as a dietary supplement and as a component of semen extenders (Fatoba *et al.*, 2013; Doidar *et al.*, 2018; Iqbal *et al.*, 2022). Research has shown that *Moringa oleifera* leaf extract (MOLE) reduces oxidative stress in semen, improving post-thaw semen quality and fertility (Dafaalla *et al.*, 2016; Iqbal *et al.*, 2022). However, at higher concentrations (>0.56 mg/ml), Moringa may decrease antioxidant capacity and cause sperm membrane damage (Carrera-Chávez *et al.*, 2020; Shokry *et al.*, 2021). Higher concentrations of *Moringa oleifera* leaf extract significantly enhanced antimicrobial activity and improved semen quality in tris-EYC extender during refrigerated preservation up to 72 hours (Chatley *et al.*, 2025). In conclusion, *Moringa oleifera*, particularly when supplemented with zinc, offers a promising approach for improving semen quality and fertility by enhancing motility, viability, acrosomal integrity, and antioxidant capacity, making it a valuable addition to Livestock reproductive management.

Future study on *Moringa oleifera* and semen quality should optimize dosage and delivery by species, investigate molecular mechanisms enhancing sperm function and cryoprotection, and assess long-term effects on fertility. Studies should also evaluate toxicity at high doses and synergistic effects with other antioxidants. Figure 7 summarizes the protective mechanisms by which *Moringa oleifera* improves semen quality, highlighting its antioxidant, and membrane-stabilizing roles that enhance motility, viability, and fertility.

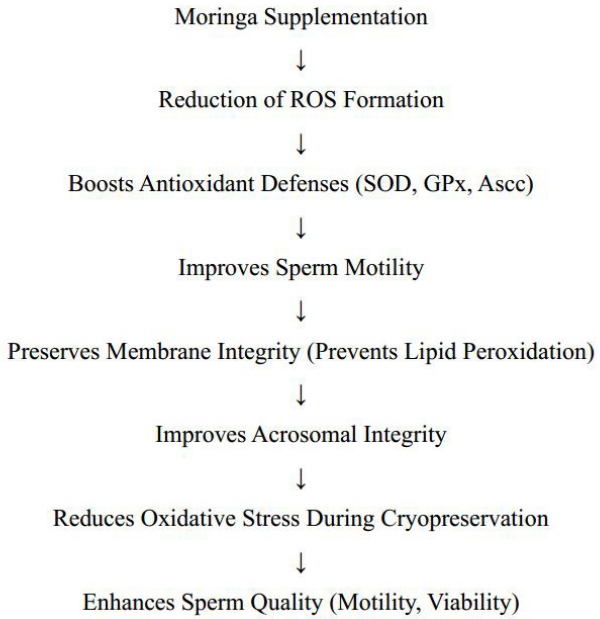

Figure 7: Protective effects of moringa on sperm function and quality.

Effect of Moringa on Hormone Production

The impact of *Moringa oleifera* on hormone production and reproductive health is dosage dependent. Moringa leaf extract has been demonstrated to enhance sexual activity, regulate reproductive hormone levels, and improve testicular morphology in heat-stressed rats (Afolabi *et al*., 2013; Prabsattroo *et al*., 2015; Venkatesh *et al*., 2019; Ogunlade *et al*., 2022). In cattle, Moringa influences uterine contractions and modulates the estrous cycle (Tripathi, 2015), while its flavonoids interact with steroid hormone systems to improve reproductive performance in herbivores (Oberdörster *et al*., 2001). Moringa also alters rumen metabolites and steroid hormone levels in goats (Liang *et al*., 2023). Moringa oil (MO) and its nano-emulsion (NMO) significantly increase testosterone levels in both serum and seminal plasma (Ismail *et al*., 2025), while Moringa seed extract reduces progesterone levels in heat-stressed female rabbits (Mutwedu *et al*., 2022). Supplementing cow diets with dried Moringa leaves increases testosterone, a key hormone for spermatogenesis (Syarifuddin *et al*., 2017), and the zinc in moringa stimulates Leydig cells to produce testosterone (Moyo *et al*., 2011).

Moringa has been shown to increase testosterone and gonadotropins, with studies indicating its effects on luteinizing hormone (LH) and follicle-stimulating hormone (FSH) gene expression in rabbit bucks (Khalifa *et al*., 2016) and bulls (Wafa *et al*., 2017; Syarifuddin *et al*., 2017). Furthermore, moringa raises LH and FSH levels in New Zealand White (NZW) rabbit bucks (Ajuogu *et al*., 2018). Moringa exhibits differential effects on male and female reproductive hormones, reducing LH, FSH, and estrogen in females, while increasing FSH, LH, and testosterone in males (Albasher *et al*., 2021; Ajuogu *et al*., 2019; El-Desoky *et al*., 2017). It appears to have a stronger effect on male reproduction (El-Gindy *et al*., 2023; Abd *et al*., 2020; Ogunlade *et al*., 2022), improving male fertility in obese rats (Greish *et al*., 2021) and enhancing LH levels and spermatogenesis in bucks (Zeng *et al*., 2019; Jimoh *et al*., 2021). Oral administration of moringa at 50 mg/kg for 100 days increases testosterone levels in rats (Akunna *et al*., 2012). While some studies report mixed results, with moringa both increasing testosterone (Suarni *et al*., 2019; Rokana *et al*., 2022) and reducing reproductive hormones in rabbits (Ajuogu *et al*., 2019), Moringa leaves are rich in essential nutrients, including amino acids, fatty acids, macro-minerals, and vitamins, which contribute to spermatogenesis (Moyo *et al*., 2011; USDA, 2015). Zinc in Moringa promotes testosterone production, although a 4% Moringa leaf diet had no effect on testosterone levels in mice (Zeng *et al*., 2019). Herbal supplements, including *M. oleifera*, improve semen quality, male sex hormones, and sperm viability (Jimoh *et al*., 2021; Noh *et al*., 2020), while vitamin C in moringa prevents sperm agglutination, thereby promoting motility (Glenville, 2008). *Moringa oleifera* demonstrates significant potential for enhancing male reproductive health, particularly through its effects on testosterone, gonadotropins, and semen quality.

Further investigations on *Moringa oleifera* and hormone production should conduct dose-response studies across species and sexes, explore its effects on the hypothalamic-pituitary-gonadal axis, and assess long-term, form-specific, and sex-specific responses. Molecular studies on hormone gene expression and interactions with metabolic and stress pathways are essential. Figure 8 illustrates the hormonal pathways and reproductive targets influenced by *Moringa oleifera*, highlighting its regulatory effects on testosterone, LH, FSH, and overall reproductive health across sexes and species.

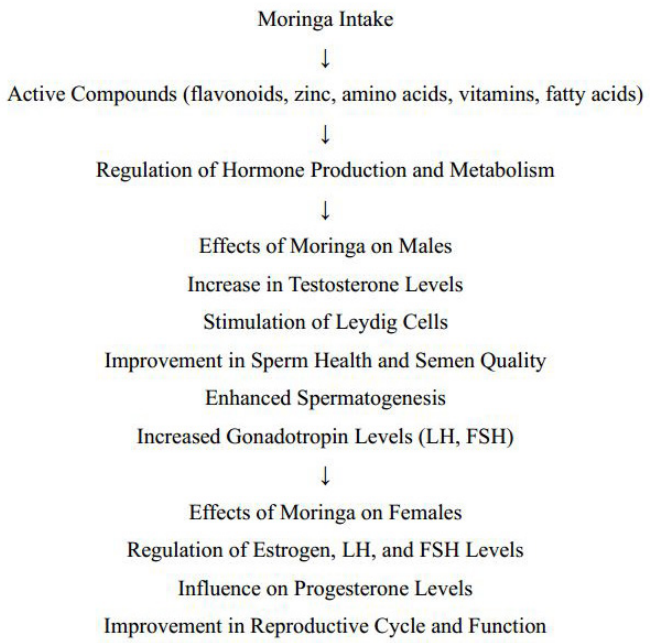

Figure 8: Effects of *Moringa oleifera* on hormonal regulation and reproductive health.

CONCLUSIONS AND RECOMMENDATIONS

This review provides a comprehensive synthesis of current knowledge on *Moringa oleifera* as a natural feed supplement in Livestock, emphasizing its positive effects on growth performance, milk and meat production, semen quality, and hormonal regulation across various species. The bioactive compounds in Moringa—such as antioxidants, flavonoids, and saponins—play key roles in enhancing physiological functions, reproductive traits, and endocrine responses.

Moringa's antioxidant properties help reduce oxidative stress, improve semen quality, increase testosterone levels,

and support spermatogenesis, thereby promoting male reproductive health and fertility. Additionally, moringa supplementation contributes to overall animal health by promoting growth, improving milk and meat production, and regulating hormonal activity, which can optimize breeding outcomes and productivity in Livestock and poultry.

However, despite increasing interest, significant knowledge gaps remain. These include the lack of standardized dosages and preparation methods, inconsistent data on reproductive and hormonal effects, limited understanding of the underlying endocrine mechanisms, and minimal focus on female reproductive performance. Moreover, the long-term safety, potential anti-nutritional effects (such as phytates, tannins, and oxalates), nutrient variability, and palatability at higher doses have not been thoroughly explored.

The forms of moringa supplementation vary widely—from green leaf and leaf extracts to powder-resulting in differences in bioactive compound concentrations and thus affecting the overall efficacy of supplementation. This variability highlights the need to identify the most suitable forms and establish optimal dosages tailored to species, breeds, and production systems. Future research should prioritize:

- Mechanistic studies to elucidate molecular pathways related to hormonal regulation, gut health, rumen fermentation, oxidative stress, and reproductive function.
- Controlled trials on reproductive parameters, including a stronger focus on female fertility.
- Dose optimization and standardization of moringa preparations for safety and efficacy.
- Long-term evaluations of health, productivity, milk and meat quality, and economic feasibility.
- Exploration of moringa's interactions with other feeds ingredients.
- Conservation and sustainable cultivation practices to support agroforestry and responsible use.

Addressing these areas will be essential to fully harness the potential of *Moringa oleifera* in sustainable animal agriculture, improving Livestock performance and reproductive management while considering environmental and consumer-related sustainability.

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NOVELTY STATEMENTS

This review uniquely integrates current evidence on Moringa oleifera as a natural feed supplement, emphasizing its multifaceted effects on livestock growth, milk and meat quality, semen parameters, and hormonal regulation. Unlike prior works focusing on isolated traits, it synthesizes findings on Moringa's bioactive compounds—such as antioxidants, flavonoids, and zinc—and their roles in enhancing feed efficiency, immune status, sperm function, and reproductive hormones (e.g., testosterone, LH, FSH). Novel insights include its impact on oxidative stress mitigation, cryopreservation outcomes, methane emission reduction, and sex-specific hormonal responses. The review also identifies research gaps in dosage standardization, form-specific effects, and long-term safety, offering critical direction for sustainable application in animal production.

AUTHOR'S CONTRIBUTIONS

Both authors contributed equally to this work.

Conflict of Interest

The authors declare no conflict of interest.

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