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Moringa Leaf Silage: A Local Feed Innovation to Improve Boer Goat Meat Quality

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ABSTRACT

Moringa oleifera leaf silage (MLS) has emerged as a promising local feed resource for small ruminant production systems in tropical regions due to its high crude protein content, balanced amino acid profile, and abundance of bioactive antioxidant compounds. This study evaluated the effects of dietary inclusion of MLS on growth performance, carcass characteristics, and meat quality attributes of growing goats. Twenty-four male Boer goats were assigned to either a control diet based on conventional forage and concentrate or a diet supplemented with MLS for a 12-week feeding period. Parameters assessed included average daily gain, carcass weight, proximate composition of meat, fatty acid profile, and lipid oxidation levels. Goats fed MLS exhibited significantly higher growth performance and carcass yield compared with the control group. Moreover, MLS supplementation improved intramuscular fat content and modified the fatty acid composition of goat meat, characterized by increased oleic and linoleic acid levels and a reduced n-6/n-3 ratio. Lipid oxidation values were significantly lower in meat from goats receiving MLS, indicating enhanced oxidative stability. These findings demonstrate that Moringa leaf silage can serve as a sustainable and locally available feed innovation capable of improving goat meat quality while reducing reliance on conventional protein sources. The use of MLS offers substantial potential for enhancing both livestock productivity and meat nutritional value in smallholder farming systems.

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INTRODUCTION

Goat production plays a crucial role in ensuring food security and supporting rural livelihoods, particularly in developing and tropical regions where livestock systems are closely integrated with smallholder farming (Teixeira et al., 2020). Goats are highly valued due to their remarkable adaptability to harsh environmental conditions, tolerance to heat stress, resistance to diseases, and relatively low maintenance requirements compared with other ruminants. In addition, goats are capable of efficiently utilizing a wide range of forage resources, including low-quality roughages and browse species, which enables them to survive and produce under marginal conditions. These adaptive characteristics make goats an essential livestock species for smallholder farmers, especially in areas with limited land resources and fluctuating climatic conditions. Goat meat also contributes significantly to household nutrition as an important source of high-quality animal protein, essential minerals, and vitamins, while generally containing lower fat levels compared to meat from other ruminant species (Aregheore, 2002).

Despite their adaptive advantages, productivity and meat quality in goat production systems remain relatively low. One of the major constraints is the inadequate and inconsistent availability of high-quality feed, particularly during the dry season when forage quantity and nutritional value decline substantially. Smallholder farmers commonly rely on natural pastures, crop residues, and agricultural by-products that are often deficient in protein, energy, and essential micronutrients. As a result, goats frequently exhibit reduced growth rates, poor feed efficiency, and suboptimal carcass yield. Although conventional protein supplements such as soybean meal and commercial concentrates can enhance animal performance, their high cost, price volatility, and limited accessibility restrict their adoption in small-scale production systems. This situation underscores the urgent need to identify alternative feed resources that are locally available, nutritionally adequate, economically affordable, and environmentally sustainable (Aregheore, 2002; Kholif et al., 2020).

Moringa oleifera is a fast-growing, drought-tolerant multipurpose tree that is widely distributed across tropical and subtropical regions (Abdoun et al., 2023; Mahfuz et al., 2019). Its leaves are characterized by a high nutritional value, containing approximately 20–30% crude protein on a dry matter basis, balanced essential amino acids, substantial levels of minerals and vitamins, and a wide range of bioactive compounds such as phenolics, flavonoids, and carotenoids (Ramachandran et al., 1985; Siddhuraju & Becker, 2003). These nutritional and functional properties have attracted increasing attention to the use of *M. oleifera* leaves as a non-conventional protein source for ruminant feeding (Abdoun et al., 2023). Numerous studies have demonstrated that fresh or dried Moringa leaves can partially replace conventional protein supplements in goat and sheep diets without compromising feed intake, nutrient digestibility, or growth performance, while in some cases improving feed efficiency and metabolic status (Aregheore, 2002; Achmadi et al., 2023; Leitanthem et al., 2023; Kholif et al., 2020)..

However, the utilization of fresh Moringa leaves in practical feeding systems is often constrained by seasonal availability, rapid deterioration after harvesting, and labor-intensive collection and processing (Abdoun et al., 2023; Mahfuz et al., 2019). Ensiling Moringa leaves represents a practical and efficient strategy to overcome these limitations by improving feed preservation, reducing post-harvest nutrient losses, and ensuring year-round feed availability. Properly prepared Moringa leaf silage (MLS) has been reported to maintain high nutritional quality and palatability, making it suitable for inclusion in goat diets under tropical production conditions (Kholif et al., 2020; Leitanthem et al., 2023). Previous research on MLS and other Moringa-based feed products has predominantly focused on their effects on growth performance, nutrient utilization, milk yield, and milk composition in small ruminants. These studies have consistently reported improvements in feed efficiency, enhanced milk protein content, and increased antioxidant capacity of animal products (Qwele et al., 2013; Moyo et al., 2023; Siddhuraju & Becker, 2003).

In contrast, relatively limited attention has been given to the effects of MLS on goat meat quality, despite increasing consumer awareness and demand for healthier and nutritionally improved meat products (Teixeira et al., 2020). Meat quality attributes such as intramuscular fat content, fatty acid composition, and oxidative stability are critical determinants of sensory characteristics, shelf life, and overall consumer acceptance (Teixeira et al., 2020; Mashau et al., 2021). Although goat meat is widely perceived as lean and nutritious, its low intramuscular fat content and susceptibility to lipid oxidation can adversely affect tenderness, flavor, and storage stability. Dietary manipulation has been recognized as a key strategy for improving meat quality, particularly through the use of plant-based feed ingredients rich in natural antioxidants and functional compounds (Mahfuz et al., 2019; Siddhuraju & Becker, 2003).

The inclusion of Moringa leaves in ruminant diets has been associated with modifications in lipid metabolism, potentially increasing the deposition of monounsaturated and polyunsaturated fatty acids while reducing the proportion of saturated fatty acids in muscle tissues. These effects are believed to be mediated by the antioxidant compounds present in Moringa leaves, which may influence rumen microbial activity and lipid biohydrogenation processes, as well as protect muscle lipids from oxidative damage (Siddhuraju & Becker, 2003; Mahfuz et al., 2019; Moyo et al., 2023). Such changes are of particular importance given the growing emphasis on producing meat with improved nutritional profiles and enhanced health benefits for consumers (Teixeira et al., 2020). Nevertheless, empirical evidence specifically addressing the impact of Moringa oleifera leaf silage on carcass characteristics, fatty acid composition, and oxidative stability of goat meat remains scarce and fragmented (Kholif et al., 2020; Abdoun et al., 2023).

Therefore, this study was designed to comprehensively evaluate the effects of dietary inclusion of *Moringa oleifera* leaf silage on growth performance, carcass traits, and key meat quality attributes of goats. It was hypothesized that supplementation with MLS would not only support improved animal performance and carcass yield but also enhance meat nutritional quality and oxidative stability (Kholif et al., 2020; Moyo et al., 2023). The findings of this study are expected to provide valuable scientific evidence supporting the use of MLS as a sustainable, locally based feeding strategy for smallholder goat production systems in tropical regions, while contributing to the broader goals of food security, rural livelihoods, and environmentally responsible livestock production (Mahfuz et al., 2019; Abdoun et al., 2023).

METHODS

The control group was fed a conventional basal diet consisting of grass hay and a commercial concentrate formulated to meet the nutrient requirements of growing goats, while the treatment group received the same basal diet supplemented with *Moringa oleifera* leaf silage (MLS) at 20% of total dietary dry matter intake. The commercial concentrate used in this study was Hi-Pro Goat Concentrate, produced by PT Charoen Pokphand Indonesia Tbk (Indonesia) and purchased from an authorized animal feed distributor in Bogor, West Java, Indonesia, formulated to meet the nutrient requirements of growing goats according to NRC recommendations (NRC, 2007). Diets were offered twice daily, and feed refusals were collected and weighed daily to determine voluntary feed intake.

Moringa oleifera leaves were obtained from community-grown *Moringa* trees located in Bogor Regency, West Java, Indonesia, where the plants were cultivated under natural conditions without the application of chemical fertilizers or pesticides. Leaves were harvested at the vegetative stage, chopped into small pieces (approximately 2–3 cm), and mixed with molasses at 5% on a dry matter basis to enhance fermentation. The molasses used for silage preparation was Cane Molasses, supplied by PT Perkebunan Nusantara VI (PTPN VI), Indonesia, and purchased from a local agricultural supplier in Bogor, West Java, Indonesia. The mixture was compacted into airtight plastic silos and allowed to ferment under anaerobic conditions for 30 days before being incorporated into the experimental diets (Kholif et al., 2020; Abdoun et al., 2023).

Feed intake was recorded daily, and body weight was measured biweekly using a digital livestock scale prior to morning feeding to minimize variation due to gut fill. Growth performance parameters, including average daily gain and feed efficiency, were calculated based on feed intake and body weight data. At the end of the feeding trial, goats were fasted for approximately 12 hours with free access to water and slaughtered following standard humane procedures. Hot carcass weight was recorded immediately after slaughter, and carcasses were chilled in a refrigerated carcass chiller at 4°C for 24 hours at a licensed slaughter facility in Bogor, West Java, Indonesia (Teixeira et al., 2020).

After chilling, samples of the *Longissimus dorsi* muscle were excised from the left side of each carcass between the 12th and 13th ribs. Muscle samples were individually vacuum-packed in sterile polyethylene bags, placed in insulated ice boxes containing ice packs, and transported to the Animal Nutrition and Meat Science Laboratory, Faculty of Animal Science, IPB University (Bogor Agricultural University), Bogor, West Java, Indonesia. Upon arrival at the laboratory, samples were stored at −20°C until further chemical and fatty acid analyses were conducted (Qwele et al., 2013; Mashau et al., 2021).

Meat samples were analyzed for proximate composition, including moisture, crude protein, intramuscular fat, and ash content, using standard methods of the Association of Official Analytical Chemists (AOAC, 2019). Fatty acid profiles were determined by gas chromatography following lipid extraction and methylation, while lipid oxidation was assessed using thiobarbituric acid reactive substances (TBARS) analysis and expressed as mg malondialdehyde per kg of meat (Siddhuraju & Becker, 2003).

RESULTS

1. Growth Performance and Carcass Characteristics of Goats

This section presents the effects of feeding a control diet and a diet supplemented with *Moringa oleifera* leaf silage (MLS) on growth performance and carcass characteristics of goats. Parameters evaluated include body weight changes, average daily gain, carcass weight, and dressing percentage to assess the impact of MLS inclusion on productive performance and carcass yield.

Table 1. Growth Performance and Carcass Characteristics of Goats

Parameter	Control	MLS (20% DM)	p-value
Initial body weight (kg)	20.1 ± 1.9	20.0 ± 2.1	>0.05
Final body weight (kg)	27.8 ± 2.3	30.6 ± 2.5	<0.05
Average daily gain (g/day)	91.4 ± 8.6	124.7 ± 10.2	<0.01
Carcass weight (kg)	12.9 ± 1.1	14.8 ± 1.3	<0.05
Dressing percentage (%)	46.4 ± 2.0	48.9 ± 2.3	<0.05

Based on the table, the MLS (20% DM) treatment did not show a significant difference in the initial body weight of the livestock ($p > 0.05$), indicating that the initial condition of the livestock in both groups was relatively homogeneous. However, the administration of MLS (20% DM) significantly affected the final body weight, average daily gain, carcass weight, and carcass percentage compared to the control group ($p < 0.05$–0.01). This indicates that the use of MLS at the 20% dry matter level can significantly improve the growth performance and carcass yield of livestock..

2. Proximate Composition of Longissimus Dorsi Muscle from Goats

This section describes the proximate composition of the *Longissimus dorsi* muscle from goats fed the control diet and the diet supplemented. Parameters analyzed include moisture, crude protein, intramuscular fat, and ash content to evaluate the effects of MLS inclusion on the chemical composition of goat meat.

Table 2. Proximate Composition of Longissimus Dorsi Muscle from Goats

Parameter (%)	Control	MLS (20% DM)	p-value
Moisture	73.6 ± 1.5	72.9 ± 1.4	>0.05
Crude protein	20.8 ± 0.9	21.1 ± 1.0	>0.05
Intramuscular fat	3.1 ± 0.4	4.2 ± 0.6	<0.01
Ash	1.2 ± 0.1	1.3 ± 0.1	>0.05

Based on the table 2, the administration of MLS (20% DM) did not significantly affect the moisture content, crude protein, and ash content of the meat ($p > 0.05$). However, the MLS treatment (20% DM) significantly increased intramuscular fat content compared to the control group ($p < 0.01$). These results indicate that the use of MLS at the 20% dry matter level can improve meat quality by increasing intramuscular fat content without changing other major chemical components.

3. Fatty Acid Profile (% of total fatty acids) of Goat

This section presents the effects supplementation on the fatty acid profile of goat meat, expressed as a percentage of total fatty acids. Changes in individual fatty acids, as well as total saturated, monounsaturated, and polyunsaturated fatty acids and the n-6/n-3 ratio, are evaluated to assess the nutritional quality of the meat.

Table 3. Fatty Acid Profile (% of total fatty acids) of Goat

Fatty acid	Control	MLS (20% DM)	p-value
Palmitic acid (C16:0)	24.6 ± 1.8	22.9 ± 1.6	<0.05
Stearic acid (C18:0)	18.2 ± 1.5	17.4 ± 1.3	>0.05
Oleic acid (C18:1)	36.8 ± 2.2	40.7 ± 2.5	<0.01
Linoleic acid (C18:2)	8.9 ± 1.1	11.6 ± 1.3	<0.01
Total SFA	44.1 ± 2.6	40.8 ± 2.4	<0.05
Total MUFA	38.7 ± 2.3	42.9 ± 2.6	<0.01
Total PUFA	12.4 ± 1.5	15.9 ± 1.7	<0.01
n-6/n-3 ratio	7.2 ± 0.8	4.9 ± 0.6	<0.01

Based on the table, the administration of MLS (20% DM) significantly affected the fatty acid profile of meat. MLS treatment reduced the levels of palmitic acid (C16:0) and total saturated fatty acids (SFA) ($p < 0.05$), and increased the levels of oleic acid (C18:1), linoleic acid (C18:2), total MUFA, and total PUFA significantly ($p < 0.01$). In addition, the n-6/n-3 ratio in the MLS group (20% DM) was lower than the control ($p < 0.01$), indicating an improvement in the nutritional quality of meat fat. Meanwhile, the levels of stearic acid (C18:0) were not significantly different between the two treatments ($p > 0.05$).

4. Lipid Oxidation (TBARS, mg MDA/kg meat) of Goat Meat

This section evaluates lipid oxidation in goat meat from goats fed the control diet and those supplemented with (MLS), as measured by thiobarbituric acid reactive substances (TBARS). The results indicate the extent of oxidative stability of meat during storage and the potential antioxidant effects of MLS supplementation.

Table 4. Lipid Oxidation (TBARS, mg MDA/kg meat) of Goat Meat

Storage time (days)	Control	MLS (20% DM)	p-value
0	0.42 ± 0.05	0.31 ± 0.04	<0.05
3	0.68 ± 0.07	0.49 ± 0.06	<0.01
7	1.02 ± 0.09	0.71 ± 0.08	<0.01

Based on the table, the observed parameter values increased with increasing storage time in both treatments. However, the administration of MLS (20% DM) resulted in significantly lower values than the control group on day 0 ($p < 0.05$), and significantly lower on days 3 and 7 of storage ($p < 0.01$). These results indicate that the use of MLS (20% DM) is able to suppress the increase in parameter values during storage, thus potentially improving product stability and quality during the storage period.

DISCUSSION

The improved growth performance and carcass characteristics observed in goats fed *Moringa oleifera* leaf silage (MLS) can be primarily attributed to the high crude protein content, balanced amino acid profile, and high nutrient digestibility of *Moringa* leaves. Several studies have reported that *M. oleifera* leaves contain 20–30% crude protein on a dry matter basis, along with essential minerals and vitamins that support muscle growth and metabolic efficiency in small ruminants (Ramachandran et al., 1985; Abdoun et al., 2023). Previous feeding trials in goats and sheep demonstrated that partial replacement of conventional protein sources with *Moringa* leaves improved average daily gain and feed efficiency, which is consistent with the enhanced growth performance observed in the present study (Aregheore, 2002; Achmadi et al., 2023; Leitanthem et al., 2023).

The increase in intramuscular fat content and favorable modification of fatty acid composition in goats fed MLS align with earlier findings indicating that dietary inclusion of plant-based feed ingredients rich in bioactive compounds can influence lipid metabolism in ruminant muscle tissues. Studies have shown that *Moringa* supplementation may increase the proportion of monounsaturated and polyunsaturated fatty acids while reducing saturated fatty acids, potentially through modulation of rumen microbial biohydrogenation and lipid synthesis pathways (Qwele et al., 2013; Sultana et al., 2020; Kholif et al., 2020). Such changes in fatty acid composition are considered beneficial from a human nutrition perspective and contribute positively to meat quality and consumer health perception (Teixeira et al., 2020).

Furthermore, the reduction in lipid oxidation observed in MLS-fed goats highlights the important role of natural antioxidants present in *Moringa* leaves, including phenolic compounds, flavonoids, and carotenoids. These compounds have been widely reported to possess strong free radical–scavenging activity and the ability to protect muscle lipids from oxidative degradation during storage (Siddhuraju & Becker, 2003; Moyo et al., 2023). Improved oxidative stability is a critical determinant of meat shelf life, sensory attributes, and overall consumer acceptance, as lipid oxidation is closely associated with off-flavor development and color deterioration (Mashau et al., 2021; Teixeira et al., 2020). Therefore, the enhanced oxidative stability observed in this study has important implications for extending the shelf life and marketability of goat meat.

Overall, the present findings support the use of *Moringa oleifera* leaf silage as a functional and sustainable feed ingredient capable of improving growth performance, carcass yield, and meat quality in goats. The combination of high nutritional value and antioxidant properties makes MLS particularly suitable for smallholder production systems in tropical regions, where access to high-quality commercial feed resources is often limited. These results are in line with previous reports advocating the integration of locally available, plant-based feed resources to enhance livestock productivity while supporting food security, rural livelihoods, and environmentally responsible livestock production (Mahfuz et al., 2019; Abdoun et al., 2023).

CONCLUSIONS

Moringa oleifera leaf silage (MLS) represents a promising local feed innovation that can be effectively utilized to improve growth performance, carcass characteristics, and meat quality of goats. The inclusion of MLS in goat diets contributes to higher body weight gain, improved carcass yield, and enhanced dressing percentage, indicating better nutrient utilization and overall production efficiency. In addition, MLS positively influences meat chemical composition by increasing intramuscular fat content, which is associated with improved palatability and consumer acceptability.

Furthermore, the use of MLS markedly improves the fatty acid profile of goat meat, as evidenced by increased proportions of monounsaturated and polyunsaturated fatty acids and a reduced n-6/n-3 fatty acid ratio. These changes are considered beneficial from a human health perspective, as they are associated with reduced risks of cardiovascular diseases. MLS supplementation also enhances the oxidative stability of meat during storage, likely due to the presence of natural antioxidants and bioactive compounds in *Moringa oleifera* leaves, which help delay lipid oxidation and maintain meat quality.

Overall, the incorporation of MLS into goat feeding strategies demonstrates strong potential to support sustainable goat production systems in tropical regions. By utilizing locally available resources, MLS can reduce dependence on conventional feed ingredients, lower production costs, and promote environmentally friendly livestock practices, while simultaneously delivering higher-quality animal products for consumers.

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