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Research article

Enhancing Growth and Nutritional Components of Hydroponic Mulato II Grass Using Moringa Leaf Extract as a Priming Agent

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Abstract: Forage grasses are vital for livestock nutrition and sustainability but face challenges due to climate change and land degradation. This study aimed to enhance the germination, growth, and nutritional quality of Mulato II grass by utilizing *Moringa oleifera* leaf extract (MLE) as a priming agent. A Completely Randomized Design (CRD) was employed, testing five treatments (unprimed seeds, hydropriming, and MLE priming for 6, 12, and 18 hours), and each treatment was replicated three times. Growth parameters, biomass, and nutritional composition were analyzed statistically at a 5% significance level, with post-hoc comparisons performed using Tukey's Honestly Significant Difference (HSD) test. MLE priming for 18 hours significantly ($p<0.05$) enhanced performance, yielding the highest vigor index (5326.67), fresh herbage yield (196.32 t/ha), and DM yield (57.70 t/ha). Nutritional analysis revealed a significant difference ($p < 0.0001$) in ether extract (EE) content (4.54%) with MLE priming for 12 hours, while crude protein content (16.76%) and total nitrogen content (3.05%) were significantly higher with MLE priming for 18 hours. Hydropriming and MLE priming for 18 hours also significantly ($p = 0.0137$) achieved the highest final emergence percentage (FEP = 53.33%). The findings show that MLE priming, especially when primed for 18 hours, significantly enhances the growth and nutritional value of Mulato II grass. It is recommended as a sustainable strategy for improving forage production, with future studies focusing on long-term effects and cost-effective scaling.

Keywords: Hydroponic; MLE; Mulato II; nutritional component; priming agent

1. Introduction

Forage grasses are essential for livestock production because they provide essential nutrients that enhance animal health, productivity, and the livelihoods of millions of farmers worldwide. The world population currently stands at 8.16 billion and is expected to continue growing in the coming years [1]. As a result, the demand for livestock products will also increase. However, there will be a reduction in land available for agricultural production due to land conversion to residential and commercial spaces, which will affect the forage supply chain in the future. In 2022, the global market for forage was valued at USD 773.12 million, and it is projected to continue increasing to US$131.0 billion by 2032 [2, 3]. Globally, 80% of the land, or 38 million km^2, is occupied or devoted to grazing and crops used for animal feed [4]. However, the global forage supply is facing a significant decrease due to the effects of traditional farming practices, such as pesticide pollution, land degradation,

population growth, loss of biodiversity, and climate change [3]. In the Philippines, this issue of declining forage supply is severe, with inconsistent forage availability threatening the sustainability of livestock farming—a vital sector for food security and rural economies [5]. Forages are essential not only for livestock nutrition but also for the overall health of the agricultural economy. They promote sustainable farming practices and enhance food security [6].

Climate change was affecting all countries, exacerbating the crisis of forage supply in the market, and impacting the livestock industry. These environmental stressors reduce forage quality and availability, increase feed costs, and lower livestock productivity [7]. In light of these challenges, innovative strategies are needed to enhance forage production, particularly in resource-limited environments. Michalk et al [8] pointed out that land conversion is one of the reasons for the declining supply of forages. One of the strategies adopted by some livestock farmers is the use of improved forage grass, which contains a high amount of essential nutrients the animals need to grow, utilizing only a small portion of the land. However, farmers often face the drawback of these improved forage grasses due to poor germination rates, which hampers the feed needed for their animals. Mulato II is one of the forage grasses yet to be widely cultivated in the Philippines. This three-way hybrid *(Urochloa ruziziensis x Urochloa decumbens x Urochloa brizantha)* is a yielding and nutritious perennial forage grass suitable for both large and small ruminants, promoting increased beef and milk production. According to the study by Bacorro et al [9], Mulato II contains 18.54-21.04% dry matter, 8.08-12.86% crude protein, 53.36-63.73% neutral detergent fiber (NDF), 30.25-38.93% acid detergent fiber (ADF), 0.23-0.30% phosphorus, and 0.21-0.37% calcium.

Seed priming has emerged as a promising technique to improve germination, growth, and stress resilience in various crops. *Moringa oleifera*, known for its rich content of growth-promoting compounds like zeatin (a cytokinin), ascorbic acid, phenolic compounds, and other antioxidants, has gained attention as a natural priming agent [10]. A study by Shrey et al. [11] has shown that moringa leaf extract can enhance seedling vigor, root development, and biomass in crops such as maize, and improve the growth performance of tomato and bell pepper. A similar result was obtained by Muneeba et al. [12], who found that moringa leaf extract enhances wheat seedling growth and mitigates salinity stress, indicating its potential to improve crop vigor and biomass in wheat. Studies have also demonstrated that moringa leaf extract can increase photosynthetic activity [13], delay senescence [14], and improve nutrient uptake [15] in treated crops and plants. Additionally, based on analysis conducted by Yasmeen et al. (2013), Moringa leaf extract contains 191.86 units of superoxide dismutase, 7.09 units of catalase, 21.99 units of peroxidase (IU/mg protein), 8.19 mg g–1 total phenolics, 0.36 mmol g–1 ascorbic acid, and 1.40 mg g–1 total soluble protein.

Despite these promising results, the application of moringa leaf extract (MLE) in forage grass production, particularly under hydroponic systems, remains underexplored. Previous studies have primarily focused on staple crops, such as maize, rice, and wheat, as well as vegetables, with limited evidence on how MLE affects the germination, growth, and nutritional composition of forage grasses. Furthermore, most existing work has concentrated on soil-based cultivation, leaving a knowledge gap regarding its potential in controlled, soilless systems, such as hydroponics, which are increasingly relevant in land- and resource-constrained environments. This study aims to address this gap by investigating the effects of MLE as a priming agent on the growth and nutritional value of hydroponically grown Mulato II grass—a promising but underutilized forage species in the Philippines. By sustainably enhancing forage production, this study aligns with several of the United Nations' Sustainable Development Goals (SDGs), including Zero Hunger (SDG 2), Climate Action (SDG 13), and Life on Land (SDG 15). Enhancing forage availability fosters more resilient livestock systems, mitigates the environmental footprint of feed production, and promotes sustainable land use practices, ultimately contributing to global food security and environmental sustainability.

2. Methodology

2.1 Site and Seed Selection

The study was conducted at the lower campus of Visayas State University in Baybay City, Leyte, Philippines, which has a microclimate characterized by localized atmospheric conditions differing from the surrounding climate. During the study, the average environmental conditions at the university were 28 °C temperature, 85.5% relative humidity, and a photoperiod of 11.8 hours per day. Mulato II grass was used as the forage material in this study. The seeds for this forage grass were procured from an online store through the Shopee shopping application. This forage grass was selected because it represented a new, improved variety that had never been tested under the conditions at Visayas State University, Baybay City, Leyte, Philippines.

2.2. Treatment Preparation

Moringa leaves were collected from the Department of Animal Science laboratory field. The leaves were separated from the stalks and primary veins and then thoroughly washed under running water using a strainer to remove insects and dirt. The cleaned leaves were extracted using a locally made hydraulic coconut presser. The extract was filtered through cheesecloth to remove any remaining particulates. After filtration, the Moringa leaf extract was stored overnight at 4°C in the Visayas State University, Baybay City, Leyte, Philippines, Department of Agronomy Laboratory refrigerator, which maintained freezing temperatures.

Figure 1 Moringa leaf extraction.

2.3 Seed Priming

Seeds of Mulato II were subjected to priming at room temperature using a 1:10 diluted Moringa leaf extract, following the method outlined in the study by Yasmeen et al. [16]. For uniformity, seeds were soaked in 44 mL of diluted extract. The soaking durations were varied: 6, 12, and 18 hours, as described by Ranmeechai et al [17]. In addition, hydropriming was performed for a 12-hour soaking duration for comparative analysis. Some Mulato II seeds were included as control samples without priming. After the priming treatments, the seeds were dried on a paper sheet at room temperature for 48 hours to restore them to their original weight.

2.4 Planting and Management

Both primed and unprimed Mulato II seeds were placed in a seedling tray for germination. The soil media in the seedling tray consisted of a mixture of garden soil and vermicast. After 15 days, healthy seedlings were selected and directly transplanted into plastic cups, each filled with coco peat, with one seedling per cup. Seedlings were chosen based on uniformity in height, absence of visible damage, and normal leaf color after 15 days of germination. The cups were placed in a Styrofoam box containing 14 liters of nutrient solution with a dilution rate of 2 mL per liter of water. The nutrient solution was enriched with essential macronutrients, including carbon, phosphorus, iron, hydrogen, nitrogen, oxygen, sulfur, potassium, magnesium, and calcium, which supported plant growth and development. Each Styrofoam box contained three plastic cups. These cups were harvested after 30 days to evaluate shoot and root development, plant vigor, and the analysis of nutritional components. The 30-day harvesting time was anchored on the standard forage evaluation intervals

to capture early biomass accumulation and nutritional quality [18]. Regular monitoring ensured that the coco peat remained moist until the roots made contact with the nutrient-rich water solution.

2.5 Seed Emergence

Seedling emergence was counted daily until the final emergence was reached. The formula from the studies by Yasmeen et al. [16] and Vujošević et al. [19] was adopted to compute the emergence index (EI), mean emergence time (MET), and final emergence percentage (FEP).

$$\text{Emergence Index} = \frac{\text{No.of emerged seeds}}{\text{Days of the first count}} + \ldots\ldots + \frac{\text{No.of emerged seeds}}{\text{Days of the final count}} \quad (1)$$

$$\text{Mean Emergence Time} = \frac{\sum(\text{Dn})}{\sum \text{n}} \quad (2)$$

where D represents the number of days from the emergence, and n is the number of seeds that emerged on each respective day.

$$\text{Final Emergence Percentage } \frac{\text{No.of emerged seeds}}{\text{Number of seeds sown}} \text{ x } 100 \quad (3)$$

2.6 Vigor Index and Growth Parameters Determination

After 30 days of emergence, plants per treatment were harvested to assess plant vigor and forage grass quality parameters. Plant height, shoot length, and root length were measured from the tip to the base using a ruler. Fresh and dry weights were determined using an analytical digital scale. Seed vigor was calculated using the formula developed by Abdul-Baki and Alderson [20].

$$\text{Vigor Index} = (\text{Shoot length} + \text{Root length}) \text{ x Germination Percentage} \quad (4)$$

The number of leaves and tillers was recorded by counting them 30 days after transplanting. Fresh herbage yield was determined by weighing the harvested parts at 30 days, while dry matter (DM) yield was calculated by multiplying the fresh weight by the DM percentage.

$$\text{DM yield} = \text{Fresh Weight x Dry Matter Percentage} \quad (5)$$

To facilitate comparison with standard agronomic studies, the yields recorded in grams per plant were extrapolated to tons per hectare, allowing for a direct comparison with standard agronomic studies. The extrapolation was based on the planting density equivalent to the hydroponic box area and then scaled up to one hectare. This approach assumes uniform growth under field conditions. However, field validation is required to confirm the applicability of the extrapolated hectare-level yields.

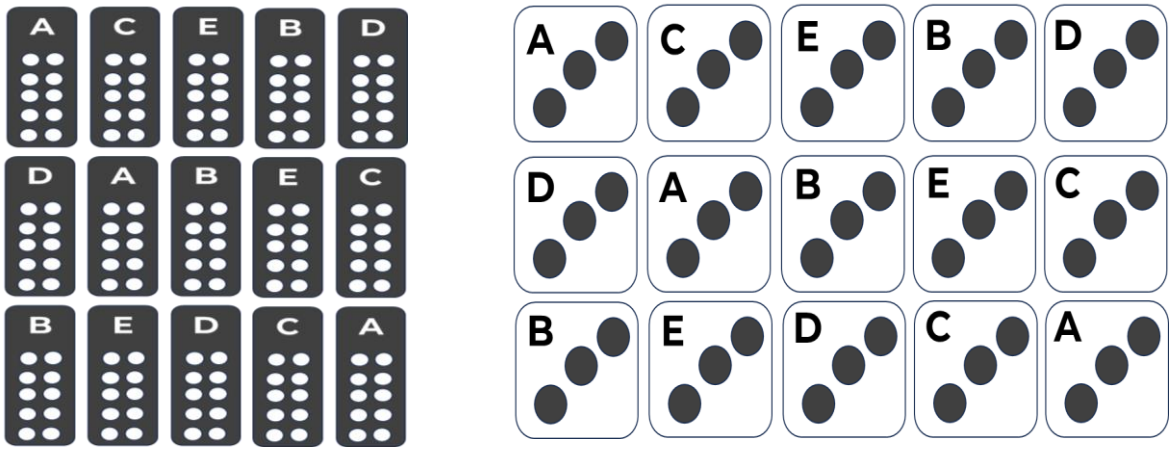
2.7 Chemical Analyses

Chemical assays involved collecting plant tissue samples from each treatment per replicate at 30 days. The samples were sent to the Visayas State University Central Analytical Laboratory for analysis of their nutrient content, including total nitrogen and available phosphorus. Other relevant parameters, including crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), and acid detergent fiber (ADF), were analyzed at the Animal Nutrition Laboratory of the Department of Animal Science. Crude protein was determined using the Kjeldahl method, ether extract by Soxhlet extraction, and NDF and ADF following the procedure of Goering and Van Soest [21].

2.8 Research Design

The study was a one-factor experiment using a Completely Randomized Design (CRD). It involved five treatments: unprimed seeds, hydropriming for 12 hours, Moringa leaf extract priming for 6 hours, Moringa leaf extract priming for 12 hours, and Moringa leaf extract priming for 18 hours, with three replicates for each treatment. For the germination phase, ten seeds of Mulato II were placed in a petri dish for each replicate. After 15 days of germination, three healthy seedlings from each replicate were selected and transferred to a prepared hydroponics set-up. The hydroponic system consisted of 15 Styrofoam boxes, each

filled with a nutrient solution at a concentration of 2 mL/L of water. Each box held 3 cups filled with a cocopeat, which served as the rooting medium for the Mulato II seedlings.



(a) Set-up for germination (b) Set-up for growth performance

Figure 2 Experimental layouts of the study

2.9 Data Analysis

The data obtained from the study were analyzed using the analysis of variance (ANOVA) in a one-factor Completely Randomized Design. The statistical analysis was performed using the PROC MIXED procedure of SAS Enterprise Guide statistical software. Significant differences among treatment means were declared at a 5% confidence level. A post hoc Test using Tukey's Honestly Significant Difference (HSD) test for pairwise comparison was conducted to determine which treatment groups differed significantly.

3. Results and Discussion

3.1 Seed emergence of Mulato II grass primed with moringa leaf extract

The seed emergence of Mulato II grass varied among treatments, including unprimed seeds, hydropriming, and priming with moringa leaf extract (MLE) for different durations. The emergence index (EI) did not show significant differences across treatments ($p = 0.1835$), with values ranging from 131.22 for seeds primed with MLE for 12 hours to 154.17 for hydropriming. The highest EI observed in hydropriming suggests that this method slightly enhanced seed vigor compared to others. Similarly, the mean emergence time (MET) showed no significant variation among treatments ($p = 0.0751$), remaining consistent between 12.15 and 12.75 days. These findings indicate that the speed of seed emergence was not notably affected by the treatments, aligning with research indicating that priming often has a limited effect on MET when seed moisture is uniformly maintained during germination [22].

Table 1. Seed emergence of Mulato II grass primed with moringa leaf extract

Treatments	Emergence Index	Mean Emergence Time	Final Emergence Percentage
Unprimed Seeds	152.20	12.27	50.00 [ab]
Hydropriming for 12 hours	154.17	12.15	53.33 [a]
Primed with Moringa leaf extract for 6 hours	144.20	12.58	50.00 [ab]
Primed with Moringa leaf extract for 12 hours	131.22	12.75	30.00 [b]
Primed with Moringa leaf extract for 18 hours	150.98	12.28	53.33 [a]
Mean	146.55	12.40	47.33
CV (%)	7.98	2.03	15.43
p-value	0.1835	0.0751	0.0137

Means with the same letter are not significantly different at (P>0.05.

However, significant differences were observed in the final emergence percentage (FEP), with a p-value of 0.0137, demonstrating that treatments substantially impacted germination success. Hydropriming for 12 hours and MLE priming for 18 hours achieved the highest FEP (53.33%), which was statistically comparable but significantly higher than the FEP of seeds primed with MLE for 12 hours (30.00%). Unprimed seeds and seeds primed with MLE for 6 hours produced intermediate FEP values of 50.00%, which were statistically comparable to those of both the highest- and lowest-performing treatments. The coefficient of variation (CV) for FEP was 15.43%, indicating moderate variability in response to the treatments. The superior FEP observed in hydropriming and MLE priming for 18 hours suggests that these treatments optimize seed hydration and metabolic activation, enhancing germination rates. MLE priming for 18 hours, in particular, benefits from bioactive compounds in Moringa, such as cytokinins, antioxidants, and vitamins, which improve seed vigor and support robust germination [23]. On the other hand, the reduced FEP seen with MLE priming for 12 hours (30.00%) may indicate insufficient uptake of these bioactive compounds or possible osmotic stress at this duration. The intermediate performance of unprimed seeds and seeds primed with MLE for 6 hours highlights the importance of optimizing priming duration to maximize the benefits of Moringa's bioactive properties. These results highlight the effectiveness of seed priming, particularly with MLE for 18 hours, as a sustainable and practical technique to enhance seed emergence in Mulato II grass. Hydropriming, while effective, lacks the added advantage of Moringa's bioactive compounds, which contribute to improved seed vigor and germination success. These findings are consistent with prior studies demonstrating that seed priming, especially with natural growth enhancers like MLE, can significantly improve germination outcomes, particularly under stress-prone environments [16].

3.2 *Vigor Index of Mulato II grass primed with moringa leaf extract.*

The vigor index of Mulato II grass was significantly influenced by seed priming treatments ($p = 0.0114$). At the same time, shoot and root lengths showed no significant differences among treatments ($p = 0.6134$ and $p = 0.0810$, respectively). For shoot length, values ranged from 56.60 cm for seeds primed with moringa leaf extract (MLE) for 12 hours to 62.37 cm for MLE priming for 18 hours, with a mean of 59.39 cm across all treatments. Root length varied more noticeably, with MLE priming for 18 hours producing the longest roots (37.17 cm) and MLE priming for 12 hours producing the shortest (25.33 cm). Although these differences were not statistically significant, the trends suggest that longer priming durations with MLE may enhance both shoot and root growth, potentially contributing to higher overall vigor. The vigor index, a composite measure of seedling quality, revealed significant differences among treatments. MLE priming for 18 hours resulted in the highest vigor index (5326.67), significantly greater than the lowest value (2458.33) observed in seeds primed with MLE for 12 hours. Unprimed seeds (4643.33), hydro-primed seeds (4822.67), and seeds primed with MLE for 6 hours (4626.67) produced intermediate vigor index values that were statistically comparable to both the highest and lowest-performing treatments.

Table 2. Vigor Index of Mulato II grass primed with moringa leaf extract

Treatments	Shoot Length (cm)	Root Length (cm)	Vigor Index
Unprimed Seeds	57.50	35.37	4643.33 ^{ab}
Hydropriming for 12 hours	60.83	29.60	4822.67 ^{ab}
Primed with Moringa leaf extract for 6 hours	59.67	32.87	4626.67 ^{ab}
Primed with Moringa leaf extract for 12 hours	56.60	25.33	2458.33 ^{b}
Primed with Moringa leaf extract for 18 hours	62.37	37.17	5326.67 ^{a}
Mean	59.39	32.07	4375.53
CV (%)	8.28	15.06	18.28
p-value	0.6134	0.0810	0.0114

Means with the same letter are not significantly different at (P>0.05.

The superior vigor index associated with MLE priming for 18 hours reflects the positive effects of Moringa's bioactive compounds, including cytokinins, vitamins, and antioxidants, which promote seedling

growth and enhance metabolic activity during germination. These properties stimulate cell division and elongation, contributing to the development of longer shoots and roots and, ultimately, higher vigor [24]. The relatively low vigor index observed in MLE priming for 12 hours may indicate suboptimal exposure to these compounds, limiting their physiological benefits or potentially creating mild osmotic stress that inhibits growth [25]. The intermediate vigor index values for unprimed, hydroprimed, and seeds primed with MLE for 6 hours highlight the importance of optimizing priming duration and the priming agent. While hydropriming can enhance seed hydration and activation of metabolic pathways, it lacks the additional growth-promoting benefits of Moringa's phytonutrients [26]. Similarly, the performance of MLE priming for 6 hours suggests that even short exposure to Moringa can improve seed vigor, although not to the same extent as longer durations. These findings emphasize the effectiveness of MLE priming for 18 hours in improving seedling vigor, offering a practical and sustainable strategy for enhancing the establishment and productivity of Mulato II grass. By leveraging the natural bioactive properties of Moringa, this technique provides a cost-effective and environmentally friendly alternative to chemical seed treatments, making it particularly valuable for resource-limited farming systems.

3.3 Average height of Mulato II grass primed with moringa leaf extract

The seed priming treatments affected the average height of Mulato II grass, with variations observed across different measurement weeks. At the initial measurement, plant heights ranged from 10.37 cm (MLE priming for 12 hours) to 14.43 cm (MLE priming for 6 hours), but the differences were not statistically significant ($p = 0.7790$). Similar trends of no significant differences continued through the first ($p = 0.4415$), second ($p = 0.2829$), third ($p = 0.0893$), and fourth weeks ($p = 0.1446$), indicating that while numerical differences were observed, they were not statistically distinct. Despite the lack of statistical significance, notable trends emerged. In the fourth week, seeds primed with MLE for 6 hours and 18 hours, respectively, exhibited the tallest plants, averaging 52.77 cm and 52.43 cm. These heights were greater than those of plants from hydroprimed seeds (48.47 cm) and unprimed seeds (41.30 cm). The lowest plant height at this stage was recorded for seeds primed with MLE for 12 hours (40.70 cm). Similar trends were observed across earlier weeks, with MLE priming for 6 hours consistently producing taller plants compared to other treatments.

Table 3. Average height (cm) of Mulato II grass primed with moringa leaf extract

Treatment	Plant height (cm)				
	Weeks				
	Initial	**1st**	**2nd**	**3rd**	**4th**
Unprimed Seeds	11.17	14.43	17.70	30.17	41.30
Hydropriming for 12 hours	11.70	15.93	20.17	32.43	48.47
Primed with Moringa leaf extract for 6 hours	14.43	20.50	26.53	43.33	52.77
Primed with Moringa leaf extract for 12 hours	10.37	13.80	17.13	28.23	40.70
Primed with Moringa leaf extract for 18 hours	11.70	16.87	22.00	38.57	52.43
Mean	11.87	16.31	20.71	34.55	47.13
CV (%)	33.78	27.71	26.22	18.96	14.56
p-value	0.7790	0.4415	0.2829	0.0893	0.1446

Means with the same letter are not significantly different at (P>0.05.

3.4 Average Number of Mulato II grass leaves primed with moringa leaf extract

The average number of leaves per plant in Mulato II grass was not significantly affected by seed priming treatments across the observation period, as indicated by the high p-values (0.9327 to 0.6819). At the initial stage, all treatments, except for seeds primed with moringa leaf extract (MLE) for 12 hours, exhibited

the same number of leaves (2.0). The exception was MLE priming for 12 hours, which yielded an average of 3.0 leaves; however, this difference was not statistically significant. By the first week, the number of leaves across treatments remained consistent, with a mean value of 3.0 leaves, regardless of the priming method. Similarly, during the second and third weeks, all treatments reached an average of 4.0 leaves, indicating uniform leaf production. By the fourth week, all treatments, except for MLE priming for 18 hours, maintained this average, with MLE priming for 18 hours resulting in a slight but non-significant reduction to 3.0 leaves. The uniformity in leaf number across treatments, including unprimed seeds, may be due to Mulato II grass's inherent genetic growth potential, which might not be significantly altered by seed priming in the short term.

Table 4. Average number of Mulato II grass leaves primed with moringa leaf extract.

Treatment	Number of Leaves				
	Weeks				
	Initial	**1st**	**2nd**	**3rd**	**4th**
Unprimed Seeds	2.0	3.0	4.0	4.0	4.0
Hydropriming for 12 hours	2.0	3.0	4.0	4.0	4.0
Primed with Moringa leaf extract for 6 hours	2.0	4.0	4.0	4.0	4.0
Primed with Moringa leaf extract for 12 hours	3.0	3.0	4.0	4.0	4.0
Primed with Moringa leaf extract for 18 hours	2.0	3.00	4.0	3.0	4.0
Mean	2.0	3.0	4.0	4.0	4.0
CV (%)	24.06	15.49	14.34	13.59	16.08
p-value	0.9327	0.6554	0.0886	0.2428	0.6819

Means with the same letter are not significantly different at (P>0.05.

3.5 Average Number of Mulato II grass tillers primed with moringa leaf extract

The number of tillers in Mulato II grass varied across treatments, with significant differences emerging during the later weeks of observation. Initially and during the first and second weeks, there were no significant differences among treatments ($p = 0.5121$ and $p = 0.4516$, respectively), with all treatments producing an average of one tiller. This similarity suggests that the priming treatments had a minimal influence on the early establishment phase of the grass, consistent with findings that priming effects are more pronounced as plants transition to active growth stages [27]. By the third week, significant differences among treatments were observed ($p = 0.0470$). Seeds primed with moringa leaf extract (MLE) for 6 and 18 hours produced three tillers, which were statistically comparable and significantly higher than the one tiller produced by seeds primed with MLE for 12 hours. Unprimed and hydro-primed seeds exhibited intermediate tiller numbers (two tillers each), statistically comparable to those of the highest- and lowest-performing treatments. The differences became more pronounced in the fourth week ($p = 0.0023$), where seeds primed with MLE for 18 hours produced the highest number of tillers (five tillers), significantly outperforming all other treatments. Seeds primed with MLE for 6 hours produced four tillers, statistically comparable to the 18-hour treatment but significantly greater than those observed in both unprimed seeds and seeds primed with MLE for 12 hours. Hydroprimed seeds produced three intermediate tillers and were statistically comparable to the other treatments. The coefficient of variation (CV) for tiller counts decreased from the third to the fourth week (35.34% to 18.98%), reflecting reduced variability as treatments exerted more pronounced effects on plant growth. The superior performance of MLE priming for 18 hours can be attributed to the bioactive compounds in Moringa, such as cytokinins, antioxidants, and nutrients, which enhance cell division, metabolic activity, and overall plant vigor [28]. These compounds likely promote more robust root and shoot development, facilitating better nutrient uptake and tillering. The intermediate performance of MLE priming for 6 hours suggests that even shorter priming durations provide benefits, though optimal results are achieved with 18-hour priming. Conversely, the reduced tiller counts observed with MLE priming for 12 hours may indicate

suboptimal exposure to Moringa's bioactive compounds, which could cause osmotic stress or inadequate physiological stimulation [29].

Table 5. Average number of Mulato II grass tillers primed with moringa leaf extract.

Treatment	Number of Tillers				
	Weeks				
	Initial	1st	2nd	3rd	4th
Unprimed Seeds	0.0	1.0	1.0	2.0 ab	2.0 c
Hydropriming for 12 hours	0.0	0.0	1.0	2.0 ab	3.0 abc
Primed with Moringa leaf extract for 6 hours	0.0	1.0	1.0	3.0 a	4.0 ab
Primed with Moringa leaf extract for 12 hours	0.0	0.0	1.0	1.0 b	2.0 c
Primed with Moringa leaf extract for 18 hours	0.0	1.0	1.0	3.0 a	5.0 a
Mean		1.0	1.0	2.0	4.0
CV (%)		36.07	24.21	35.34	18.98
p-value		0.5121	0.4516	0.0470	0.0023

Means with the same letter are not significantly different at (P>0.05.

These findings highlight the effectiveness of MLE priming, particularly for 18 hours, in improving the vegetative growth of Mulato II grass. The increase in tiller production reflects enhanced plant vigor and potential biomass, which are crucial for forage production. Hydropriming, while beneficial, lacked the additional growth-promoting effects of MLE, reaffirming the role of bioactive compounds in optimizing plant performance.

3.6 Herbage yield of Mulato II grass primed with moringa leaf extract

The herbage yield of Mulato II grass was significantly influenced by seed priming treatments, as indicated by both fresh and dry yield data. For fresh herbage yield, seeds primed with moringa leaf extract (MLE) for 18 hours produced the highest yield (196.32 t/ha), which was significantly greater than other treatments but statistically comparable to seeds primed with MLE for 6 hours (164.39 t/ha). In contrast, unprimed seeds had the lowest fresh herbage yield (78.95 t/ha). Hydropriming for 12 hours (115.44 t/ha) and MLE priming for 12 hours (116.93 t/ha) resulted in intermediate yields comparable to each other but significantly lower than those achieved with MLE priming for 6 and 18 hours. Similarly, for dry herbage yield, MLE priming for 18 hours produced the highest yield (57.70 t/ha), significantly surpassing all other treatments but comparable to MLE priming for 6 hours (45.35 t/ha). Unprimed seeds had the lowest dry yield (25.87 t/ha), while hydropriming (31.03 t/ha) and MLE priming for 12 hours (31.77 t/ha) produced comparable yields that were significantly lower than those of the MLE treatments for 6 and 18 hours. Statistical analysis revealed significant differences among treatments, as evidenced by low p-values for fresh ($p = 0.0013$) and dry yield ($p = 0.0014$). The superior performance of MLE priming for 18 hours can be attributed to the bioactive compounds in Moringa, such as zeatin (a natural cytokinin), vitamins, minerals, and antioxidants, which enhance seed metabolism, promote vigorous germination, and stimulate growth. The high yields observed in MLE-primed seeds align with findings that cytokinin-rich treatments improve biomass accumulation by promoting cell division and delaying senescence [30].

Interestingly, while MLE priming for 6 hours produced yields comparable to those of the 18-hour treatment, the slightly lower yields suggest that a longer priming duration may optimize the absorption of Moringa's bioactive compounds. Although beneficial in enhancing germination and hydration, hydropriming produced significantly lower yields than those of MLE priming treatments, emphasizing the added value of Moringa's phytonutrients [31]. Unprimed seeds consistently yielded the lowest biomass, underscoring the critical role of priming in improving herbage productivity.

Table 6. Herbage yield of Mulato II grass primed with moringa leaf extract.

Treatments	Herbage Yield (tons/ha)	
	Fresh	Dry
Unprimed Seeds	78.95 [c]	25.87 [c]
Hydropriming for 12 hours	115.44 [bc]	31.03 [bc]
Primed with Moringa leaf extract for 6 hours	164.39 [ab]	45.35 [ab]
Primed with Moringa leaf extract for 12 hours	116.93 [bc]	31.77 [bc]
Primed with Moringa leaf extract for 18 hours	196.32 [a]	57.70 [a]
Mean	134.40	38.35
CV (%)	16.27	16.23
p-value	0.0013	0.0014

Means with the same letter are not significantly different at (P>0.05.

These findings suggest that MLE priming, particularly for 18 hours, is a highly effective and sustainable strategy for enhancing both fresh and dry herbage yields of Mulato II grass. By leveraging the natural growth-promoting properties of Moringa, this approach offers a cost-effective alternative to synthetic inputs, particularly in tropical and subtropical regions where Moringa is abundant. The significant yield improvements achieved through MLE priming make it a practical solution for addressing the dual challenges of increasing forage production and promoting sustainable agriculture. The study emphasizes the potential of MLE priming to optimize forage yield and quality, benefiting resource-constrained farmers while contributing to sustainable livestock systems.

3.7 Nutritional component of Mulato II grass primed with moringa leaf extract.

The nutritional composition of Mulato II grass was influenced by seed priming treatments, with significant differences observed in ether extract (EE) content ($p < 0.0001$), crude protein (CP) content ($p < 0.0001$), and total nitrogen (TN) content ($p = 0.0001$) but no significant effects on moisture content (MC), dry matter (DM), organic matter (OM), ash, total phosphorus (TN), neutral detergent fiber (NDF), or acid detergent fiber (ADF). The moisture content ranged from 66.21% in unprimed seeds to 72.95% in seeds hydro-primed for 12 hours, with no statistically significant differences ($p = 0.6494$). Similarly, DM content varied from 27.05% (hydroprimed for 12 hours) to 33.79% (unprimed seeds), but remained statistically comparable among treatments. Likewise, OM content consistently exceeded 95% across all treatments ($p = 0.5801$). Ash content showed slight variations, ranging from 3.70% to 4.31%, but these differences were also not statistically significant ($p = 0.5801$). Ether extract (EE) content, an indicator of the fat content in the grass, exhibited significant differences among treatments. Seeds primed with moringa leaf extract (MLE) for 12 hours produced grass with the highest EE content (4.54%), significantly higher than that of all other treatments. Comparable EE values followed this in unprimed seeds (2.55%), hydroprimed seeds (2.73%), and seeds primed with MLE for 18 hours (2.34%). The lowest EE content was observed in seeds primed with MLE for 6 hours (0.63%), which was significantly lower than in all other treatments. The significant improvement in EE content following MLE priming for 12 hours can be attributed to the bioactive compounds in Moringa, such as zeatin, antioxidants, and vitamins, which may enhance lipid synthesis and accumulation in plant tissues. Similar findings have been reported by Nouman et al [25], highlighting the role of phytohormones in improving nutritional quality. However, the reduced EE content observed with MLE priming for 6 hours suggests that shorter priming durations may not allow sufficient uptake of these bioactive compounds, limiting their impact on lipid metabolism. Hydropriming and unprimed seeds resulted in intermediate EE content, indicating that while hydration enhances seed germination and subsequent growth, it lacks the additional nutritional benefits Moringa's phytonutrients provide. Crude protein (CP) content exhibited statistically significant differences across treatments ($p < 0.0001$), highlighting the impact of seed priming on protein synthesis. The highest CP content (16.76%) was recorded in grass from seeds primed with moringa leaf extract (MLE) for 18 hours, followed by 15.02% from the 6-hour priming treatment. Unprimed and hydroprimed seeds yielded intermediate CP levels (14.67% and 14.50%, respectively), while MLE priming for 12 hours resulted in the lowest CP value (14.09%). These variations are also reflected in the total nitrogen (TN)

content, which ranged from 2.56% to 3.05%. Notably, the TN content was highest in the 18-hour MLE priming treatment, aligning with its elevated CP value. This suggests that extended exposure to MLE may enhance nitrogen assimilation, likely through the synergistic action of Moringa's bioactive compounds such as cytokinins and micronutrients [21].

Table 7. Nutritional component of Mulato II grass primed with moringa leaf extract

Treatments	Nutritional Components									
	MC (%)	DM (%)	OM (%)	EE (%)	Ash (%)	CP (%)	TN (%)	TP (%)	NDF (%)	ADF (%)
Unprimed Seeds	66.21	33.79	95.69	2.55 [b]	4.31	14.67 [b]	2.67 [b]	0.25	47.77	24.47
Hydropriming for 12 hours	72.95	27.05	96.30	2.73 [b]	3.70	14.50 [b]	2.64 [b]	0.24	46.55	33.52
Primed with Moringa leaf extract for 6 hours	71.56	28.44	96.27	0.63 [c]	3.73	15.02 [b]	2.73 [b]	0.24	47.23	27.96
Primed with Moringa leaf extract for 12 hours	72.21	27.79	96.08	4.54 [a]	3.92	14.09 [b]	2.56 [b]	0.22	45.91	23.26
Primed with Moringa leaf extract for 18 hours	70.70	29.30	95.71	2.34 [b]	4.29	16.76 [a]	3.05 [a]	0.23	47.86	23.49
Mean	70.73	29.27	96.00	2.47	3.99	15.01	2.73	0.24	47.06	26.54
CV (%)	8.17	19.75	0.61	18.61	14.77	2.81	2.81	5.02	10.96	18.17
p-value	0.6494	0.6494	0.5801	<0.0001	0.5801	<0.0001	<0.0001	0.1077	0.9875	0.1171

Means with the same letter are not significantly different at (P>0.05)

Total phosphorus (TP), which is vital for energy transfer and root development, showed slight fluctuations among treatments, ranging from 0.22% to 0.25%. Though these differences were not statistically significant ($p = 0.1077$), the trend indicates a potential influence of MLE on phosphorus uptake or retention, particularly in the 6-hour priming group. The neutral detergent fiber (NDF) and acid detergent fiber (ADF) values showed no significant differences across treatments ($p = 0.9875$ and $p = 0.1171$, respectively). NDF values ranged from 45.91% in seeds primed with Moringa leaf extract for 12 hours to 47.86% in seeds primed for 18 hours. Similarly, ADF was lowest (23.26%) in seeds primed with Moringa leaf extract for 12 hours, suggesting improved digestibility due to reduced lignin and cellulose content. These findings underscore the potential of Moringa leaf extract to enhance forage quality for ruminants, particularly at optimal priming durations. The results demonstrate that seed priming, particularly with MLE priming for 12 hours, notably enhanced EE, while 18-hour priming maximized CP and TN levels. While other nutritional components, such as MC, DM, OM, Ash, TP, NDF, and ADF, remained unaffected, the marked improvement in EE, CP, and TN contents highlights the potential of MLE priming to enhance forage quality. The variation in optimal results across different priming durations may be attributed to differences in the uptake and physiological utilization of Moringa's bioactive compounds, suggesting that shorter durations may favor certain metabolic pathways, such as lipid synthesis. In contrast, longer durations are more effective in enhancing protein accumulation and nitrogen assimilation. These findings emphasize the value of MLE priming as a sustainable and cost-effective strategy for enhancing forage yield and quality, particularly in resource-constrained agricultural systems.

4. Conclusions

This study demonstrated the efficacy of MLE priming, particularly for 18 hours, in enhancing the growth performance and nutritional quality of Mulato II grass. MLE priming significantly improved key parameters, including vigor index, fresh and dry herbage yields, and final emergence percentage, compared

to unprimed seeds and hydropriming. The bioactive compounds in MLE, such as cytokinins, antioxidants, and vitamins, likely contributed to improved seed vigor, metabolic activity, and nutrient accumulation. While hydropriming was effective, it lacked the added benefits of MLE's phytonutrients. The study highlights the potential of MLE priming as a sustainable and eco-friendly strategy for enhancing forage production in controlled environments, such as hydroponics. Based on the results, MLE priming for 18 hours is recommended for maximizing seed vigor, nutrient contents, and forage yield. Further research could investigate other durations and concentrations to refine this practice. Field-based studies should be conducted to validate the effectiveness of MLE priming under real-world conditions, including different environmental stresses. To ensure widespread adoption, a detailed economic assessment of MLE extraction and application should be performed, particularly in resource-limited farming systems. Future research should also investigate the impact of MLE priming on plant growth and forage quality across multiple crop cycles to assess its sustainability and productivity. The application of MLE priming could be extended to other forage crops to evaluate its broader potential in improving livestock nutrition and sustainable agriculture. Additionally, combining MLE priming with advanced hydroponic techniques and nutrient management strategies could further enhance forage productivity and quality.

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