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Morphological Adaptation and Biomass Partitioning of Upland Rice (*Oryza sativa* L.) Seedling Treated with *Moringa oleifera* Leaf Extract Under Drought Stress

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Abstract. *Drought stress is the primary abiotic constraint that inhibits growth and reduces the productivity of upland rice (Oryza sativa L.). This study aimed to evaluate the effectiveness of various concentrations of moringa leaf extract (Moringa oleifera L.) used as a biostimulant and plant-based antitranspirant in mitigating the effects of drought stress on the morphological adaptation and biomass partitioning of upland rice seedlings. The study was conducted in a greenhouse using a two-factor completely randomized design (CRD), where the stress factor consisted of three levels: 100% field capacity (FC) as the control, 60% FC, and 30% FC. The second factor was the concentration of the moringa leaf extract applied via foliar spray, at levels of 0%, 2.5%, 5%, and 7.5%, respectively. The parameters observed included plant height, root length, fresh weight, and dry weight of the seedlings. The results of the analysis of variance and the 5% LSD test showed that the application of moringa leaf extract significantly improved the morphological parameter of plant height and enhanced the plants' tolerance mechanism to drought stress by regulating root elongation as a mechanism to avoid drought stress. A 7.5% moringa leaf extract concentration was found to be the most optimal, resulting in the highest plant height (23.8 cm), the slowest root length growth rate, and the highest dry weight (0.3144 g) per plant under drought-stressed conditions. The application of a 7.5% moringa leaf extract is recommended to improve the drought tolerance of upland rice and maintain its early growth performance. It is recommended to conduct application trials with higher concentrations.*

Keywords: *Biomass; Drought stress; Moringa leaf extract; Morphological Adaptation;Upland rice.*

1. BACKGROUND

Upland rice (Oryza sativa L.) is a strategic food commodity cultivated on dryland to support national food security. The development of upland rice is the best alternative for supporting food security and production, given that rice production in paddy fields faces constraints due to limited land availability. The fundamental constraint on the development of upland rice productivity is ecophysiological factors, in which plant growth and production are limited by abiotic stress, particularly water deficit or drought. Abiotic factors are ecological constraints in dryland agriculture; therefore, various technologies must be implemented to enhance plant tolerance to the effects of ecological stress. Drought stress triggers physiological and biochemical disturbances that directly inhibit cell division, reduce the rate of photosynthesis, and ultimately decrease morphological growth and plant biomass accumulation (Kapoor *et al*., 2020; Zhang *et al*., 2021).

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To mitigate the negative impacts of drought, an environmentally friendly agrotechnological approach is needed, specifically, the application of technologies based on an agroecophysiological approach. One such effort involves the application of plant-based biostimulants that also act as antitranspirants. These biostimulants can serve as a source of nutrients, minerals, and active compounds that enhance plant tolerance to stress. One natural compound that can be utilized, for example, is Moringa oleifera leaf extract (MLE). Moringa leaves have been recognized as having great potential in enhancing plant tolerance to abiotic stress. Moringa leaf extract is rich in phytohormones, antioxidants, minerals, and osmoregulatory compounds relevant to stress tolerance (Islam *et al*., 2022). The content of endogenous phytohormones (particularly zeatin from the cytokinin group), antioxidants (ascorbic acid), and osmolytes helps maintain cell turgor, delays leaf senescence, and suppresses excessive transpiration rates under water-deficient conditions (Khan *et al*., 2023). The potential of this moringa leaf extract will be examined in the early growth of upland rice by observing morphological aspects and the resulting biomass accumulation as the plant's morphophysiological response to the treatment administered.

Although the potential of moringa leaf extract has been extensively studied, specific information regarding the effect of moringa leaf extract concentrations on biomass partitioning and the morphological architecture of upland rice seedlings under drought stress conditions remains limited.

2. THEORETICAL OVERVIEW

Numerous studies support moringa oleifera leaf extract (MLE) as a biostimulant that enhances plant tolerance to abiotic stress, primarily through three main pathways: its bioactive composition, physiological mechanisms, and evidence of efficacy in stressed plants. Several studies have reported that cytokinins in MLE are present as zeatin, dihydrozeatin, and isopentyladenine, with zeatin at high concentrations, while ascorbate, glutathione, β-carotene, tocopherol, and various vitamins are also abundant (Islam *et al*., 2022; Arif *et al*., 2022). Several studies have also confirmed that moringa leaves themselves are a source of phenolics, flavonoids, sugars, proline, and essential nutrients that contribute to their biostimulant effects (Perez *et al*., 2027; Hajaji *et al*., 2024).

When plants experience drought stress, the application of MLE tends to improve the plants' water status, strengthen the antioxidant system, and stabilize cell membranes and photosynthesis (Islam *et al*., 2022; El-Mageed *et al*., 2017; Pervez *et al*., 2017). Foliar application of MLE to rice plants, particularly during the active vegetative growth phase, enhances gas exchange and photosynthetic pigments; these effects are associated with the content of zeatin, ascorbate, phenolics, and other metabolites in moringa leaves (Khan *et al*., 2023; Kadir *et al*., 2026). Observations indicate that MLE maintains relative water content, water-use efficiency, osmoprotectants, and membrane integrity while reducing electrolyte leakage (El-Mageed *et al*., 2017). The most consistent effects of MLE are seen as improvements in growth, photosynthesis, and yield across various species under drought, salinity, or osmotic stress. However, the magnitude of these effects depends on the species, concentration, timing of application, and extract treatment (Islam *et al*., 2022).

In upland rice seedlings subjected to drought stress, moringa leaf extract generally improves growth, maintains water status, and shifts biomass allocation toward a more functional root and canopy system. Still, direct evidence regarding biomass partitioning in the seedling stage of upland rice remains limited and is more often inferred from changes in root-to-shoot weight, leaf area, and root architecture rather than measured as detailed allocation ratios (Kadir *et al*., 2023; Khan *et al*., 2023).

Field studies that explicitly tested the concentration of MLE applied to upland rice tend to show a positive response that increases up to an application concentration of 15% MLE, with increases in plant height, number of tillers, productive tillers, flag leaf area, number of grains, grain weight per plant, and yield under several stress levels; 15% yielded the best performance at 75% and 50% of field capacity (Ferdiansyah *et al*., 2024)

Mechanistically, several studies indicate that MLE promotes growth by maintaining plant water status, increasing chlorophyll and photosynthesis, and supporting partitioning of photosynthates, thereby allowing more of the formed biomass to be retained under drought conditions (Khan *et al*., 2023). Its use on other crops also provides consistent evidence that MLE increases fresh and dry weight of the root-shoot system, leaf area, root length, root area, and dry biomass in corn, wheat, soybeans, and greenhouse rice, suggesting a strong biological effect on the biomass partitioning of upland rice seedlings (Hanafy, 2017; Lalarukh *et al*., 2022). Greenhouse studies have shown an increase in root biomass and fine root formation of approximately 25%, supporting a more extensive root morphological architecture compared to untreated rice plants (Castro *et al*., 2026)

2. METHODS

A. Experimental Design

The study was conducted using a greenhouse experiment arranged according to a 2-factor Completely Randomized Design (CRD), where the Stress factor, as the First factor, consisted of three levels: 100% Field Capacity (FC) as the Control, 60% FC, and 30% FC. The second factor was the concentration of the *Moringa oleifera* Leaf Extract (MLE) applied via foliar spray, with levels of 0%, 2.5%, 5%, and 7.5%, respectively.

B. Research Procedure

Upland rice seeds were sown and transplanted into polybags filled with a growing medium of soil and manure (2:1). Drought stress was applied during the vegetative phase (21 days after planting) by maintaining soil moisture levels according to the respective treatments at 100% (Control), 60% field capacity (FC), and 30% FC to simulate water stress conditions. Moringa leaf extract was applied via foliar spraying (through the leaves) according to the treatment concentrations in the morning at 7-day intervals. The moringa leaf extract was obtained through pure extraction by macerating fresh moringa leaves using distilled water as the solvent, followed by filtration. The concentration formulation before application was prepared by mixing the extract with distilled water according to the specified ratio.

C. Observation Parameters and Data Analysis

The morphological and agronomic parameters observed at the end of the vegetative phase (45 days after sowing) included:

(1) *Plant Height (cm)*: Measured from the base of the stem to the tip of the tallest leaf.

(2) *Root Length (cm)*: Measured from the base of the root collar to the tip of the longest root.

(3) *Fresh and Dry Weight* (g): Plants were air-dried for 6 hours to determine Fresh Weight, then oven-dried at 70°C for 48 hours until a constant weight was reached to determine Dry Weight.

The data obtained were Tabulated using MS-Excel and then analyzed using Analysis of Variance (ANOVA). If a significant effect was found, the analysis was followed by LSD Test at a 5% significance level.

3. RESULTS AND DISCUSSION

Based on the results of the Anova, the application of various concentrations of MLE under drought stress conditions had a significant effect ($p < 0.05$) on the morphological parameters and biomass partition of upland rice, except for fresh weight.

A. Plant Height

Morphological implications of plant height were significantly affected by the application of various concentrations of moringa leaf extract under Control (no drought stress) or 100% field capacity conditions, as well as under 60% field capacity conditions; however, none of the treatment concentrations had a significant effect under high stress conditions (30% field capacity).

Table 1. Effect of various concentrations of MLE under different Drought stress levels on the plant height of Upland-rice seedlings at 25 days after sowing

MLE Concentration	% Field Capacity (Drought Stress) 100% FC	60% FC	30% FC
0 %	22.67 [c]	21.67 [b]	20.33 [a]
2.5 %	24.17 [b]	23.00 [ab]	21.67 [a]
5.0 %	25.33 [b]	23.00 [ab]	21.67 [a]
7.5 %	**26.83** [a]	**23.80** [a]	21.33 [a]
LSD		1.3777	

Different superscripts indicate significant differences (P<0.05) by LSD test

Analysis of the height of upland rice seedlings at 25 days after sowing (DAS) (Table 1), field capacity (% FC), and the concentration of MLE applied showed a significant effect ($P < 0.05$). At 100% field capacity (optimal conditions), an increase in MLE concentration was directly proportional to an increase in plant height. A 7.5% MLE concentration produced the tallest plant height of 26.83 cm, which was significantly different and higher than the 0% control (22.67 cm), 2.5% MLE (24.17 cm), and 5.0% MLE (25.33 cm). The increase in plant height at a 7.5% concentration reached 18.35% compared to plants without MLE treatment. At 60% Field Capacity (Moderate Stress), the application of 7.5% MLE maintained plant height growth up to 23.80 cm, a significant difference from the control without MLE (21.67 cm). Interestingly, the average height of rice seedlings under moderate water stress (60% FC) treated with 7.5% MLE (23.80 cm) was more than that of seedlings under optimal water conditions (100% FC) without MLE (22.67 cm). At 30% Field Capacity, all the MLE concentration treatments (0%, 2.5%, 5.0%, and 7.5%) showed no statistically significant differences (ranging from 20.33 to 21.67 cm).

A decrease in field capacity generally inhibits the height elongation of upland rice plants. Under water-stressed conditions (60% FC and 30% FC), the water potential of the growing medium decreases, thereby reducing water uptake by the roots. Water deficit in plant tissues causes a decrease in cell turgor pressure, even though turgor pressure is the primary driving force required for cell expansion and cell elongation in the apical meristem. In addition, water deficit stimulates the synthesis of abscisic acid (ABA) in the roots, which is translocated to the leaves to trigger stomatal closure. Stomatal closure reduces the rate of transpiration and restricts CO_2 uptake, thereby inhibiting the rate of photosynthesis and severely limiting the assimilates produced for vegetative growth (Abhilasha *et al*., 2021; Qiao *et al*., 2024).

The success of MLE in significantly increasing plant height at 100% FC and 60% FC was due to the abundant content of phytohormones and essential nutrients in the moringa leaf extract. However, under severe stress conditions (30% FC), there was no significant difference among the MLE concentrations. This indicates the presence of a primary limiting factor, namely the availability of water molecules themselves. Although the plants received an external supply of plant growth regulators and nutrients from MLE, the extreme water deficiency prevented plant cells from reaching the minimum turgor pressure threshold required for cell division and elongation. Physiologically, the physical process of cell elongation cannot occur without sufficient water availability to serve as a solvent and to fill the cell vacuole volume. Therefore, the application of the MLE biostimulant at concentrations up to 7.5% was unable to elicit a significant growth response when the soil was under conditions of extreme drought (30% FC).

These results indicate that applying MLE at a 7.5% concentration is the best treatment for promoting the height growth of upland rice seedlings under optimal water conditions (100% FC) and is most effective at mitigating the negative effects of drought under moderate stress conditions (60% FC). However, under conditions of extreme water stress (30% FC), the application of the MLE biostimulant needs to be combined with other water efficiency techniques (such as the application of water-retaining organic materials or hydrogels).

B. Root Length (cm)

The average root length of rice seedlings in response to the application of various concentrations of moringa leaf extract showed a significant effect under conditions of 60% Field Capacity and high stress (30% FC), however, none of the treatment concentrations had a significant effect under optimal conditions (100% FC).

Table 2. Effect of various concentrations of MLE under different stress levels on the root length of Upland rice seedlings at 25 days after sowing

MLE Concentration	% Field Capacity (Water Stress) 100% FC	60% FC	30% FC
0 %	4.50 ^{a}	7.33 ^{a}	11.50 ^{a}
2.5 %	4.67 ^{a}	6.67 ^{a}	10.33 ^{a}
5.0 %	5.00 ^{a}	6.33 ^{ab}	8.83 ^{b}
7.5 %	4.33 ^{a}	5.33 ^{b}	6.50 ^{c}
LSD		1.3023	

Different superscripts indicate significant differences ($P<0.05$) by LSD test

The data in Table 2 show the pattern of root morphology responses, where under 100% Field Capacity (Normal Conditions), the application of various MLE concentrations (0% to 7.5%) did not have a statistically significant effect on root length. The average root length fell within a relatively short range, namely 4.33 cm–5.00 cm. Under Water Stress Conditions (60% FC and 30% FC), it was observed that, in general, a decrease in field capacity triggered significant root elongation. Under 30% FC conditions without MLE, roots reached a maximum length of 11.50 cm, an increase of more than 150% compared to the 100% FC condition (4.50 cm). This indicates that water stress triggers root elongation even without MLE application. In contrast, the application of MLE under water-stressed conditions significantly suppressed primary root elongation. At 30% FC, increasing the MLE concentration from 0% to 7.5% gradually and significantly reduced root length, from 11.50 cm to 10.33 cm (2.5% in root length), 8.83 cm (5.0% in root length) to 6.50 cm (7.5% in root length).

Physiological Mechanisms of Root Elongation Under Drought Stress. The rapid root elongation observed in control plants (0% MLE) under drought stress (30% FC) represents a natural morphological adaptation mechanism (drought avoidance mechanism) in upland rice. MLE contains phytohormones, primarily zeatin, as well as antioxidants, micronutrients, amino acids, and osmolytes, which have been shown to improve plants' tolerance to drought stress consistently (Hanafy, 2017). The application of MLE supports plant growth, including root growth, and mitigates the negative effects of water deficit on various crop species (Batool et al., 2025). When water availability in the upper layer of the growing medium is limited, the plant stimulates the accumulation of the hormone abscisic acid (ABA) in the roots. ABA, together with auxin in specific proportions, triggers hydrotropism, the directed and accelerated elongation of the primary root into deeper soil layers in search of water sources (Dietrich, 2018; Aslam *et al*., 2022). ABA also maintains primary root elongation at low water potential by restricting ethylene production, preventing growth inhibition (Smith, 2018).

Evidence of the effect of MLE application in modulating root elongation lies in the roles of cytokinins and osmoregulation. The reduction in the rate of root elongation resulting from MLE application under stress conditions (60% FC and 30% FC) can be explained by the primary mechanism of cytokinin (zeatin)-mediated inhibition of root elongation, as MLE is known to be very rich in natural cytokinin hormones (particularly zeatin). Physiologically, cytokinins play dual, opposing (antagonistic) roles between the shoot and root. In the shoot, cytokinins stimulate cell division and accelerate height growth (as shown in the data in Table 1 above). In the roots, high concentrations of exogenous cytokinin inhibit primary root elongation and, conversely, stimulate the formation of lateral roots. As a result, the roots do not grow vertically but instead become shorter with denser branching.

Another effect is the reduction of water stress perception through osmoregulation, in which the content of osmolytes (such as proline and dissolved sugars), antioxidants, and the minerals calcium (Ca^{2+}) and potassium (K) in MLE help plant cells maintain turgor pressure and membrane stability (Maeruf, 2026). Biomass Partitioning implies a shoot-root relationship; a comparison of plant height data (Table 1) and root length data (Table 2) reveals a shift in assimilate allocation strategy (biomass partitioning) resulting from MLE application. Without MLE (0%) under stress conditions (30% FC), plants sacrificed shoot growth (height of only 20.33 cm) to elongate their roots (11.50 cm) for survival. With MLE (7.5%) under stress (30% FC), the plants allocated energy to maintain metabolism and shoot growth as well as the formation of a more compact root system, so that primary root elongation was limited to 6.50 cm. In contrast, plant height was maintained (21.33 cm).

The application of moringa leaf extract (MLE) under water-stressed conditions indicates that upland rice shifts its adaptation strategy from extreme primary root elongation (drought avoidance) to maintaining cell turgor and balancing shoot-root growth through the supply of exogenous cytokinins and natural osmoregulators.

C. Fresh Weight and Dry Weight (Biomass) of Plants

Statistically, based on an analysis of variance (ANOVA), the application of various concentrations of moringa leaf extract had no significant effect on the average fresh weight of upland rice seedlings. The data on the average fresh weight of the plants are shown in Figure 1.

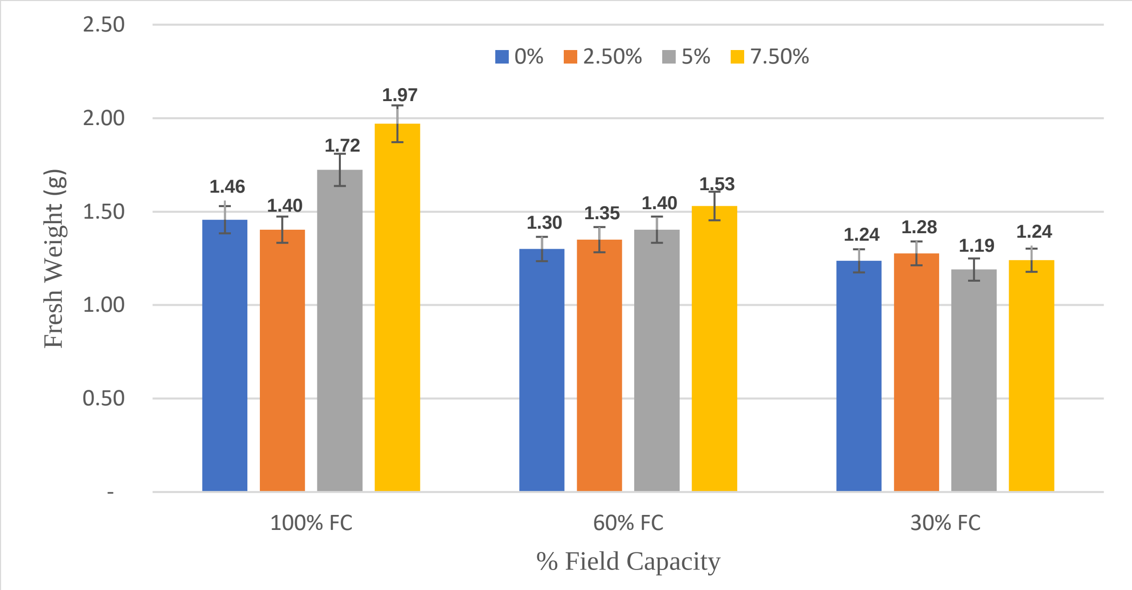

Figure 1. Average fresh weight of upland rice seedlings at 25 Days after sowing following the application of various concentrations of MLE under different stress levels

Figure 1 shows the average relative decrease in plant wet weight as field capacity decreases, indicating the presence of drought stress. The application of moringa leaf extract tended to result in an increase in average fresh weight at all field capacity levels. In general, the application of MLE concentrations was able to mitigate drastic fluctuations in fresh weight loss, especially when plants were under water stress. Fluctuations in fresh weight due to MLE concentration are consistent with actual plant morphological growth data, which are mutually supportive, such as plant height, where a 7.5% MLE concentration resulted in greater plant height and contributed to a larger canopy volume, which directly led to an increase in fresh weight.

The average dry weight (biomass) of rice seedlings resulting from the application of various concentrations of moringa leaf extract showed a significant effect under conditions of 60% field capacity and high stress (30% FC); however, none of the treatment concentrations had a significant effect under optimal conditions (100% FC).

Tabel 3. The Effect of Various Concentrations of MLE on the Dry Weight (Biomass) of Upland Rice Seedlings at 25 Days After Sowing

MLE Cocentration	Average of Biomass (g)	$LSD^{0.05}$
0 %	0.2356^{b}	
2.50 %	0.2367^{b}	0.0533
5.00 %	0.2667^{ab}	
7.50 %	0.3144^{a}	

Different superscripts indicate significant differences (P<0.05) by LSD test

Dry weight is a cumulative reflection of a plant's photosynthetic efficiency and adaptive capacity. Drought stress can drastically reduce dry weight due to disrupted carbon fixation; however, research findings indicate that the application of a 7.5% moringa extract significantly increased biomass partitioning, reaching 0.314 g per plant.

This increase in dry weight indicates that moringa extract serves a dual function: as an *osmoprotectant* that protects chlorophyll from degradation caused by oxidative stress, and as a source of additional nutrients (bionutrients) delivered via the leaves (foliar application). The ascorbic acid and phenolic compounds in moringa neutralize *Reactive Oxygen Species* (ROS) formed during drought, thereby maintaining cell membrane integrity and allowing assimilates (products of photosynthesis) to be effectively translocated to form biomass. The foliar application of MLE consistently increases plant dry weight across species by mitigating oxidative stress while providing additional nutrients (Haris *et al*, 2024; Hanafy, 2017; Lalarukh *et al*., 2022). The ascorbic acid, phenolic compounds, and phytohormones in MLE work synergistically to neutralize ROS, stabilize cell membranes, and maintain photosynthetic capacity, thereby ensuring that assimilates can continue to be translocated into biomass (Hanafy, 2017; Islam *et al*., 2022).

4. CONCLUSIONS

The application of moringa leaf extract (*Moringa oleifera*) has been shown to effectively mitigate the effects of drought stress by altering plant morphological characteristics such as plant height and suppressing the rate of root elongation as an adaptive mechanism; in this process, certain metabolites in the moringa leaf extract enhance the plants' tolerance to drought stress. The application of MLE increases the accumulation of plant dry weight. Based on the research results, a 7.5% moringa leaf extract concentration in this study was found to be the most optimal for enhancing tolerance and maintaining the growth of upland rice seedlings under drought stress conditions. However, a recommendation from this study is to test the use of higher concentrations in future plant growth experiments.

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