



Research Article

EFFECT OF MORINGA LEAF EXTRACT AND POWDER APPLICATIONS ON GROWTH AND YIELD OF WHEAT UNDER SEMI-ARID CONDITIONS

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Abstract

Ensuring global food security requires the adoption of sustainable, cost-effective bio-stimulant strategies to enhance the productivity of staple crops like wheat. This study aimed to systematically evaluate and compare the effects of foliar-applied Moringa Leaf Extract (MLE) and soil-applied Moringa Dry Leaf Powder (MDLp) on the growth and final yield of wheat (*Triticum aestivum* L.) in semi-arid environments. The experiment utilized a Randomized Complete Block Design to test various application timings, including seed treatment and foliar sprays. Results consistently demonstrated that treatments receiving foliar sprays of MLE at critical growth stages exhibited superior agronomic and yield traits. Specifically, three foliar applications of MLE (at 40, 75, and 100 days after sowing) proved most effective, increasing grain yield by over 26.82% and enhancing 1000-seed weight by 19.49% compared to the untreated control. This superior performance was driven by significant gains in key yield components, including increased tiller density, spikelets per spike, and grain number per spike. While seed treatment was beneficial for early crop growth rate, the MLE foliar application sustained higher growth rates throughout the mid-to-late season. These findings emphasize that MLE, particularly when administered through multiple foliar sprays, serves as a potent natural biostimulant that effectively enhances both the vegetative and reproductive capacity of wheat. This environmentally friendly practice offers a viable and sustainable approach to improve crop productivity in water-limited environments.

Keywords: Bio-stimulant, *Triticum aestivum*, Seed treatment, foliar nutrition.

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1. INTRODUCTION

Wheat (*Triticum aestivum*) is a cereal crop from the family poaceae and the main source of nutrition for around 40% of the global population (Li *et al.*, 2020). The history of wheat in agriculture is very long as it one of the first crops to be cultivated and it has been the main food source of Europe, West Asia, and North Africa during the last 8000 years (Velimirović *et al.*, 2021). The reason behind this is mostly because of the agronomic adaptability of wheat, storage of grain and

preparing of flour to be used in a variety of recipes is easy. Wheat is now the most common crop in the world over planted on 218 million hectares with its trade volume being higher than that of all other crops in the world. Wheat has an essential part in human nutrition, providing 20% of the daily protein and dietary calories. In the context of food security, wheat is the 2nd most important crop in the developing nations after rice, with an estimated 80 million farmers reliant on it for livelihoods (Giraldo *et al.*, 2019). Soil



salinity is the second most common cause of land deterioration after erosion, which has a substantial negative impact on agricultural production (Hossain *et al.*, 2020). It threatens to degrade up to 50% of agricultural land by the middle of the century, damaging around 1.5 million hectares of land worldwide every year (Soni *et al.*, 2021). Salinity decreases wheat yield and quality by influencing physiological and biochemical processes, such as the formation of Reactive Oxygen Species (ROS) caused by Na⁺ toxicity, which destroys important biomolecules and affects redox equilibrium (Mao *et al.*, 2023).

A well-developed root system is crucial for plant growth and development particularly in harsh environments. A study on seedling growth, phenological development, spike features, and yield components at different salinity levels revealed stunted seedling growth and delayed developmental stage. As a result, novel methods and approaches for wheat production in stressed fields must take into account wheat production that is sustainable and healthy (Yasmeen *et al.*, 2013b). Moringa is one such tree that provides numerous nutritional and medicinal benefits. It is high in macronutrients, micronutrients and other bioactive substances. The leaves are high in minerals, vitamins, amino acids and other important compounds (Mehmood *et al.*, 2022). Exogenous progression components like biological compounds minerals and antioxidants, have been found to increase crop development, growth, and plant resilience to environmental adversities, resulting in higher commercial yields (Khan, 2025). Bio-stimulants are produced naturally from organic chemicals and microorganisms which are used in agriculture (Rouphael and Colla, 2020).

The most frequent bio-stimulants are microorganisms, plant extracts, seaweed extracts, protein hydrolysates, folic acids and amino acids (Sun *et al.*, 2024). Fresh moringa

leaf extracts have important antioxidant properties because the extracts contain a large number of plant secondary metabolites especially osmoprotectants (Farhat *et al.*, 2023). Several nutrients have been identified for their ability to keep plants green and resistant to stress in MLE (Arif *et al.*, 2023). Salicylic acid a plant growth regulator which is plentiful in nature, contributes to the plant's response to challenging environment (Sharma, 2013). Ascorbic acid and associated enzymes are required for a variety of plant processes, including diversity, growth, absorption, and expansion (Smirnoff and Wheeler, 2000). It also replenishes the troposphere to protect the plant against Reactive Oxygen Species oxidative crossover of involuntary compartment (Wedow *et al.*, 2021). Additionally, hydrogen peroxide (H₂O₂) is a signal molecule that enhance the stress resistance of the plant (Sarwat and Tuteja, 2018). The main objective of this study was to assess the effect of different application methods of moringa (MLE vs. MDLp) on the agronomic performance of wheat, aiming to confirm whether both treatments significantly enhance yield and growth, and specifically to test if foliar-applied MLE offers superior benefits to physiological traits compared to applied MDLp.

2. MATERIALS AND METHODS

Experimental Site and Layout

The purpose of this study was the collection of data for the foliar application of moringa leaf extract, moringa dry leaf powder, the effects of seed treatment, on the yield and growth traits of the Fakhar-e-Bhakkar wheat cultivar. The field experiment was conducted on during 2021-22 at the Agronomic research farm, Bahauddin Zakariya University Multan, Pakistan. Seeds were dipped and coated with MDLp at a rate of 20% (w/w), meaning 20 g of powder per 100 g of seed. The sowing date of wheat was 10 December 2021 and sowing was carried out using a drill

sowing method with a seed rate of 55 kg/acre. The study utilized a randomized complete block design (RCBD) with ten treatments and three replications, resulting in a total 30 experimental plots. Recommended fertilizer dose was applied at the time of sowing and to reduce weed development during the crop's growing/life cycle, the Dab method was used instead of pesticides.

Preparation of Moringa Leaf Extract (MLE) and Powder (MDLp)

During the preparation of moringa leaf extract, young leaves were collected from several field regions in Multan district and immediately stored in a refrigerator at 15 °C up to 24 hours. The extract was prepared by blending the leaves with distilled water at a ratio of 1 kg of fresh leaves per 10 L of water. The slurry was then filtered through a muslin cloth, and the resulting filtrate (MLE stock solution) was stored at 15 °C. For all foliar spray treatments, the MLE stock was further diluted with water to achieve the final application concentration of 6% (Foidl *et al.*, 2001). Moringa leaves were collected, washed and subjected to shade drying for 6 days. The dried material was then ground into a fine powder (MDLp) (Reddy *et al.*, 2020).

Treatments

T1 = (Control).

T2 = (Once foliar spray 40 days after sowing).

T3 = (Once foliar spray 75 days after sowing).

T4 = (One foliar spray at 100 days after sowing)

T5 = (Twice foliar spray at 40+75 days)

T6 = (Twice foliar spray per 40+100 days)

T7 = (Twice foliar spray at 75+100 days)

T8 = (three foliar sprays at 40+75+100 days)

T9 = (Seed Treatment (Powder Application 20%)

T10 = Seed Treatments (Fresh Leaves Extract 20%)

Plant height (cm)

The height of wheat plants was measured by selecting ten plants at random from each plot. Each plant was measured from the base at ground level to the tip of the flag leaf on the main shoot. The average height of these ten plants was then calculated and recorded in centimeters.

Plants density per unit area (m⁻²)

The number of plants per unit area was counted during the stem elongation stage by placing a 1-meter square quadrat at three randomly selected locations within each plot. The counts from these three spots were then averaged to obtain a representative value.

Number of Tillers (m⁻²)

Productive tillers, defined as culms bearing fertile spikes, were counted using a one-meter square quadrat placed at three different spots within each plot. The values obtained were then averaged to calculate the number of tillers per square meter.

Spike length (cm)

At the crop harvesting stage, 8-10 plants from each treatment were randomly measured for spike length using a measuring tape.

Dry matter accumulation (g m⁻²)

During the developing period, a one-meter quadrat of plants was taken from three distinct locations in each plot using a sickle and averaged. Samples were dried in a 70 °C cabinet until they reached a consistent weight. The dry weight was then recorded and divided by three to calculate the average.

Crop growth rate (g m⁻² day⁻¹)

To calculate the growth rate of crop, dry weight accumulation was measured at two different stages and estimated by using formula given below (Ramesh *et al.*, 2019).

$$\text{Growth Rate Formula} = \frac{W_2 - W_1}{P (t_2 - t_1)}$$

where W1 is the plant's dry weight at time T1, T2-T1 is the number of days between them, P is the ground area, and W1 is the plant's dry weight at time T1.

Number of spikelets per spike

Grain is grown in spikelets. A higher number of spikelets results in a bigger grain number. The number of spikelets found in each spike was estimated by using twenty randomly selected wheat plant spikes following each treatment.

Numbers of grains per spike

The amount of grains in individual spikes influences overall grain output. Grain amount was determined by collecting spikes of twenty wheat plants from plots in the trial zone under study.

1000 grain weight (g)

Randomly selected from a plot's grain yield, a grain sample was weighed and recorded as 1000 grains.

Biological yield (kg m⁻²)

The biological yield was determined by taking three random quadrates of one square meter of each plot, one square meter removed with its roots and weight of the grain and straw to give the total weight of the plants. This weight was then averaged and translated to kg m⁻².

Grain yield (kg m⁻²)

After harvesting the crops, bundles of one square meter were knotted. Labor was recruited to manually thresh them, which were then weighed and translated into kg per m⁻².

3. RESULTS

Plant Height (cm)

The highest plant height (77.5 cm) was seen in T8, which received three foliar sprays at 40, 75, and 100 days after sowing and was statistically significant, presented into group 'a'. T5 (77.1 cm) came next, receiving two sprays at 40 and 75 days and being assigned to group 'ab'. T6 (76.83 cm) likewise receiving two sprays at 40 and 100 days showed a significant increase in plant height and belonged to group 'bc'. Treatments T7 (76.7 cm) was assigned in group 'b-d', T2 (76.43 cm), T3 (76.53 cm) and T9 (76.46 cm) were statistically similar within 'cd'. The lowest plant height was measured in T10

(76.4 cm), T4 (76.33 cm) and T1 (76.26 cm) which were in group 'd'. As $p \leq 0.05$ so results are considered statistically significant (Fig 1).

Number of Tillers (m⁻²) of Wheat

The treatment T6 (153.67), and T8 (153.67) and T10 (153.74) all falling into group 'a', that received two foliar sprays at 40 and 100 days, three foliar sprays at 40, 75 and 100 days after sowing and seed treatments (fresh leaves extract 20 %) respectively, having the maximum number of tillers and shows the statistically significant results. Moreover, the 20% moringa leaf extract seed treatment in treatment T10 indicates that both foliar application and moringa seed treatment have a beneficial effect on tillers development. Despite having slightly lower values, treatments T9 (153.59) belonged to group 'ab', as well as T2 (153.22) and T7(153.22) belonged to group 'a-c'. T4 (152.56, b-d) and T3 (152.44, cd) showed a progressive reduction, with both using a single foliar spray at later growth stages (100 and 75 days), which appears to be less successful (Fig 2).

The control (T1) having the small number of spikelet's (152.11) and was assigned to group 'd', indicating a statistically significant decrease when compared to the top treatments. So it was found that treatments involving numerous foliar sprays of moringa leaf extract (T5, T6, T8) or seed treatment with MLE (T10) significantly increased spikelet number as compared to the untreated control. The results were significant as at $p \leq 0.05$ under seed treatment and foliar application against control (Fig 2).

Number of Plants (m⁻²)

The maximum number of plants was seen in T5 (53.7), T8 (53.6) and T9 (53.5) which fell into the highest statistical category 'a', suggesting no significant differences between the treatments. T10 (53.3), T7 (53.2), and T6 (53.1) fared somewhat worse but were statistically equivalent, falling into

group 'ab'. T3 (52.89) was assigned to group 'a-c'. Treatments T2 (52.3) and T1 (52) were statistically lower, falling into groups 'b-d' and 'cd', respectively. T4 had the minimum number of plants (51.44), which was statistically significant and classified as 'd' (Fig 3).

Spike Length (cm) of Wheat

The longest spikes were found in T6 (9.30 cm) and T7 (9.27 cm), which were statistically significant and classified in group 'a'. T8 (9.10 cm), which involved three foliar treatments, was assigned to group 'a-c'. Treatments T2 (8.53 cm), T9 (8.53 cm), and T3 (8.50 cm) having moderate spike lengths and were assigned to group 'b-d'. T10 (8.43 cm) and T4 (8.43 cm) were marginally lower, classified as 'cd'. The shortest spikes were found in the control (T1), with an average length of 7.83 cm and placement in the lowest statistical group 'd' as shown in Fig 4.

Number of Spikelet / Spike of Wheat

The number of spikelets per spike varied significantly in different treatments. The highest spikelet count was obtained in T8 (16.66), which had three foliar sprays 40, 75 and 100 days after seeding and was statistically superior, placing it in group 'a'. Treatments T7 (14.66) T6 (14.33) and T5 (14) were statistically equivalent and assigned to group 'b', 'bc', and 'bcd' respectively. T4, T3 and T9 recording 13.66, 13.33 and 13 spikelets, followed closely and were assigned to group 'b-e', 'b-e' and 'c-f' respectively. T2 and T10 (12.66, 12.33) had moderate spikelet numbers, which were classified as 'd-f' and 'ef'. The lowest spikelet count (11.66) was seen in T1 (control) as shown in Fig 5. The study found that foliar and seed treatments significantly enhanced the number of spikelets per spike of wheat ($p \leq 0.05$) compared to the control.

Number of Grains / Spike of Wheat

T8 (50) had the maximum amount of grains per spike, had three foliar sprays at 40, 75, and 100 days after sowing, and was

statistically superior, falling into group 'a'. T7 (42.5) was classified in group 'b'. Treatments T5 (42) and T6 (41.66) were statistically similar and classified as 'bc'. T4 (40) was assigned to group 'cd'. T3 (38.06) and T2 (38) were statistically equivalent, falling into the 'de' group. T9 (36.33) was classified as 'ef', although T10 (35.5) and the control (T1 = 34.33) had the lowest grain numbers and were statistically equal, placing them in the lowest category, 'f' as shown in Fig 6. The results showed that grains per spike of wheat were considerably altered by foliar and seed treatments when compared to the control.

Biological Yield (kg m⁻²) of Wheat

Treatment T8 (Foliar spray thrice at 40, 75, and 100 days after sowing) had the highest biological yield (1.47 kg m⁻²) and was statistically significant. This shows that repeated foliar treatments during critical growth stages increased plant vigor and biomass accumulation. T5, T6, and T7 (foliar applications twice at varied combinations of 40, 75, and 100 days) were the second-best group (b), with yields ranging from 1.3080 to 1.3300 kg m⁻². This suggests that two foliar sprays were successful, albeit not as much as the triple treatment. Treatments T2, T3, T4, and T9 (single foliar sprays at 40, 75, or 100 days, and seed treatment with dry moringa powder) performed moderately (c), yielding roughly 1.23-1.24 kg m⁻² (Fig 7).

These findings show that, while moringa application at any stage outperformed control, time and frequency were critical for optimizing biomass. T10 (seed treatment with moringa extract 20%) decreased in the c group (1.23 kg m⁻²), comparable to single foliar spray treatments, indicating that seed treatment alone has a minimal influence on biological yield. T1 (Control) had the lowest biological yield (1.16 kg/m²) and showed statistically different from all other treatments (d), indicating that moringa application considerably increases biological production as shown in Fig 7.

Grain Yield (kg m⁻²) of Wheat

Grain yield of wheat was significantly influenced by the various moringa-based treatments, with distinct responses depending on the method, timing, and frequency of application. T8 (Foliar spray thrice at 40, 75, and 100 days) produced the highest grain production 0.42 kg m⁻² and was statistically superior to all other treatments (group a). This shows that consistent foliar treatment during critical growth phases considerably improves grain filling and eventual production. T5, T6, and T7 (foliar spray sprayed twice at various phases) were the next best performing treatments (group b), with grain yields between 0.37 and 0.38 kg m⁻². These findings suggest that two well-timed foliar sprays produce significant benefits over untreated control, but fewer than the triple application. T2, T3, T4, T9, and T10 (single foliar sprays and seed treatments) were placed under c, with yields ranging from 0.35 to 0.35 kg m⁻², indicating small yield gains compared to the control, but no statistically significant difference among them (Fig 8).

T1 (Control) had the lowest grain output (0.33 kg m⁻²) and was significantly different from all treatments (group d), indicating that moringa administration, whether foliar or seed-based, improves grain production as shown in Fig 8. As $p \leq 0.05$ so results are considered statistically significant.

Thousand Grain Weight (g) of Wheat

The use of moringa leaf extract and dry powder at various treatment times and procedures had a significant impact on 1000 seed weight, an important yield component representing seed size and grain filling efficiency. T8 (Foliar spray three times at 40, 75, and 100 days) had the highest 1000 grain weight (51.37 g) and was statistically superior (group a) to all other treatments. This suggests that regular foliar treatments offered constant nutritional and hormonal support, increasing grain filling and

producing larger, healthier seeds. T5, T6, and T7 (foliar sprays applied twice) resulted in significantly greater seed weights (45-45.28 g) and were classified as 'cd', 'c', 'b' respectively indicating that two well-timed foliar applications were successful in enhancing seed development, but not as much as three.

T2 (de), T3 (c), T4 (e), T9 (c), and T10 (ef) exhibited moderate increases in seed weight ranging from 43.927 to 44.3 g, demonstrating that single foliar sprays or seed treatments had a limited but beneficial impact on grain size. T1 (Control) had the lowest 1000 seed weight (42.97 g) and was statistically the weakest (group d), demonstrating that moringa treatments promote seed growth as shown in Fig 9.

Crop growth rate 1st (20 days' interval after the application of first treatment)

T9 (Seed treatment with moringa dry leaf powder 20%) achieved the highest CGR (0.7933 g m⁻²/day) and was statistically superior to group 'a'. This suggests that dry moringa powder applied as a seed treatment provided a high early growth stimulation, most likely due to its nutrient-rich composition and growth-promoting chemicals, which improved seedling vigor and biomass accumulation. T10 (Seed treatment with moringa leaf extract 20%) showed a CGR of 0.76 g m⁻²/day, statistically put in group ab, indicating that liquid extract had a beneficial influence on early crop growth, but slightly less than powder form.

T2, T5, T6, and T8 (foliar sprays once or twice) comprised the next group 'b' with CGR values ranging from 0.74 to 0.75 g m⁻²/day. This suggests that early foliar application of moringa extract successfully promoted growth, probably because to improved photosynthesis and metabolic activity. T1 (Control) had the lowest CGR (0.62 g m⁻²/day) and was classified as 'c', indicating that the absence of therapy impaired early growth performance. T3, T7, and T10 (CGR values

between 0.64 and 0.65 g m⁻²/day) were also in group 'c', indicating that later or less frequent foliar applications had no significant impact on early growth compared to seed treatments or early foliar sprays as shown in Fig 10.

Crop growth rate 2nd (20 days' interval after the application of second treatment)

The crop growth rate evaluated after the second treatment application represents sustained or increased biomass accumulation during the mid-growth stages, as impacted by moringa-based treatments. T8 (Foliar spray thrice at 40, 75, and 100 days) had the highest CGR (0.78 g m⁻²/day) and was statistically superior to group 'a'. This suggests that consistent foliar application during key developmental stages improves growth rate by extending nutrient and hormone availability.

T5 (Foliar spray twice at 40 and 75 days) achieved CGR of 0.7767 g m⁻²/day, placing it in group 'ab' which suggests that early and mid-stage treatments can support maintain strong growth and biomass accumulation. T9 (Seed treatment with moringa dry leaf powder) performed well (0.75 g m⁻²/day) and was placed in group a-c, demonstrating that an early boost in seed vigor can have long-term impacts during the mid-phase of crop growth. T10 (seed treatment with moringa extract) and T2, T6, T7 (foliar applications at different phases) were the middle-performing group ('cd' to 'd'), with CGR values ranging from 0.72 to 0.74 g m⁻²/day, showing moderate success in maintaining crop growth at this time. Single foliar sprays at 75 (T3) and 100 days (T4) showed reduced CGR values (0.71 and 0.66 g m⁻²/day, respectively), as shown in Fig 10 indicating that a single late application is insufficient to maintain strong growth rates.

Crop growth rate 3rd (20 days' interval after the application of third treatment)

The 3rd CGR measurement indicates late-season vegetative growth during grain filling, an important step for final biomass and yield formation. At this stage treatment remained effective in terms of crop growth. T8 (Foliar spray at 40, 75, and 100 days) had the highest CGR (0.91 g m⁻²/day) and was put in group 'a', indicating that continuous foliar spraying during all main growth phases enhance biomass accumulation and yield until maturity. T7 (foliar application at 75 and 100 days), T6 (foliar application at 40 and 100 days), and T5 (foliar application at 40 and 75 days) resulted in CGR values of 0.83, 0.82 and 0.81 g m⁻²/day respectively and were placed in same group 'bc'.

This demonstrates that two timely foliar sprays can effectively maintain strong crop growth in later stages, particularly when managed at or around the grain-filling period. T9 (Seed treatment with moringa dry powder) remained beneficial with a CGR of 0.79 g m⁻²/day, indicating that seed treatment had a long-term positive impact on crop development, even in late season. T10 (Seed treatment with moringa extract) had a slightly lower CGR (0.78 g m⁻²/day, group 'cd'), indicating benefit but less long-lasting effect compared to the powder form.

T4 (Foliar spray once at 100 days) showed modest performance (0.76 g/m²/day, group 'de'), indicating that a single late foliar spray can boost growth, but not as much as repeated treatments. T2 and T3 (single sprays at 40 and 75 days, respectively) were in group 'e' with CGRs of 0.74 g/m²/day, indicating a modest influence by the third growth interval. T1 (Control) had the lowest CGR (0.69 g m⁻²/day) and was in group 'f' as shown in Fig 10, showing considerably lower late-season growth without moringa treatment.

The mean values for all growth parameters, including plant height, No. of tillers and No. of plants, are presented in Table 1.

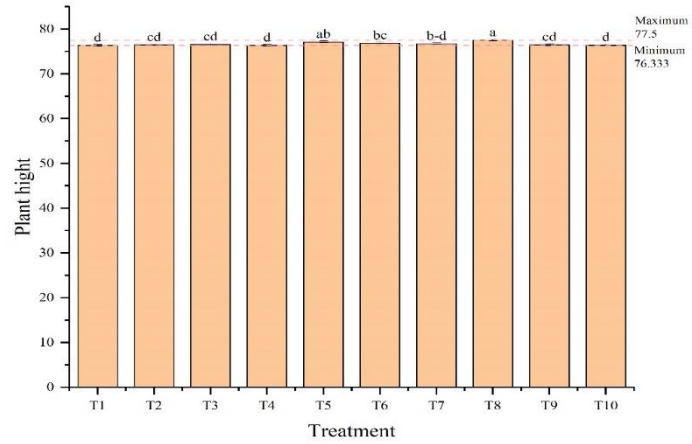


Figure 1: Impact on plant height (cm) of wheat in 10 different treatments

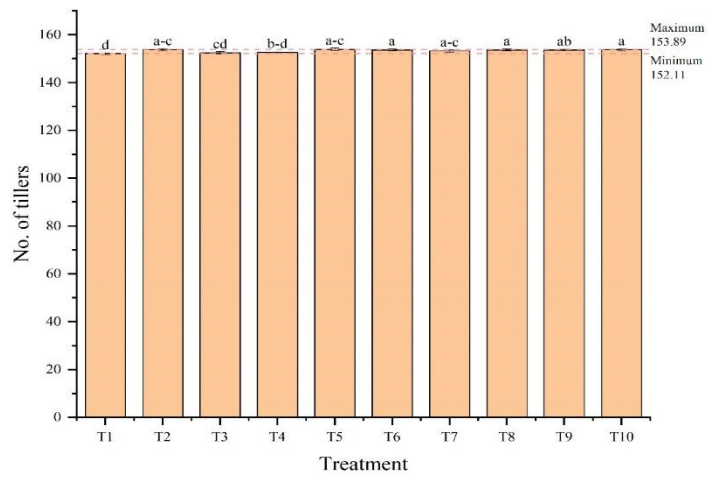


Figure 2: Impact on number of tillers (m⁻²) of wheat in 10 different treatments

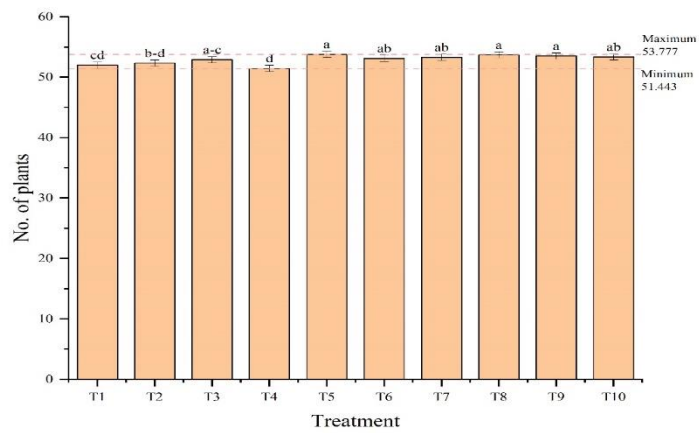


Figure 3: Impact on number of plants (m⁻²) in 10 different treatments

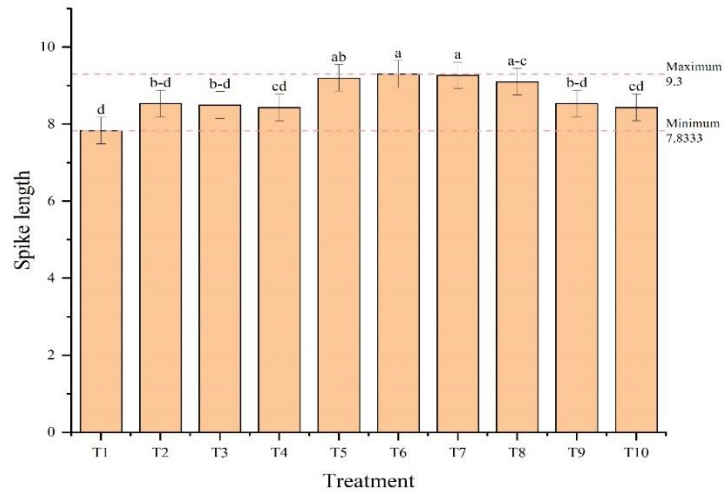


Figure 4: Impact on spike length (cm) of wheat in 10 different treatments

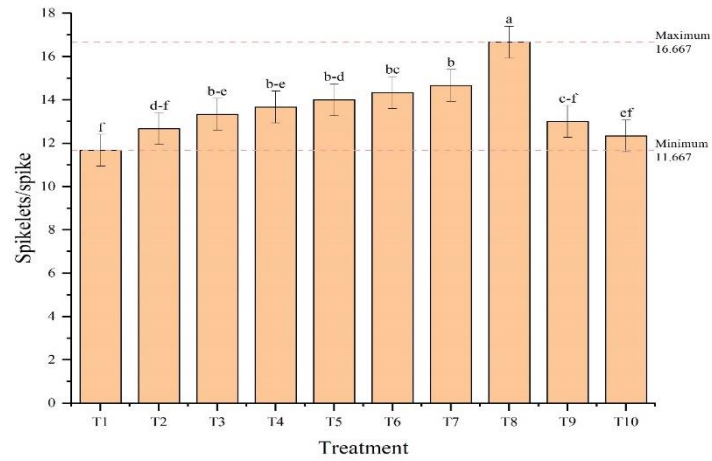


Figure 5: Impact on number of spikelet/spike of wheat in 10 different treatments

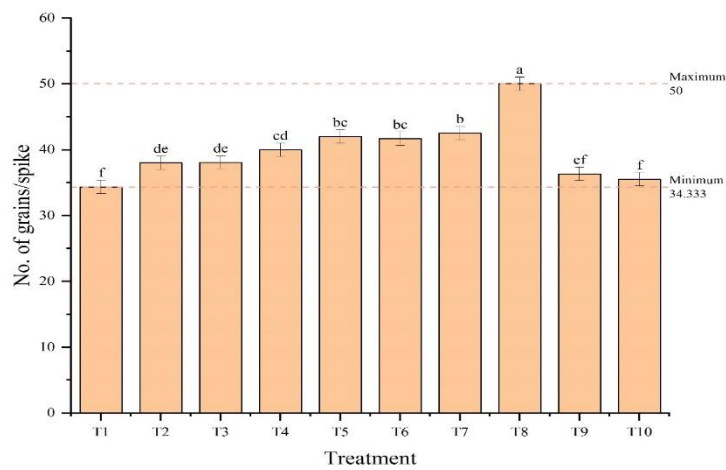


Figure 6: Impact on number of Grains / Spike of Wheat in 10 different treatments

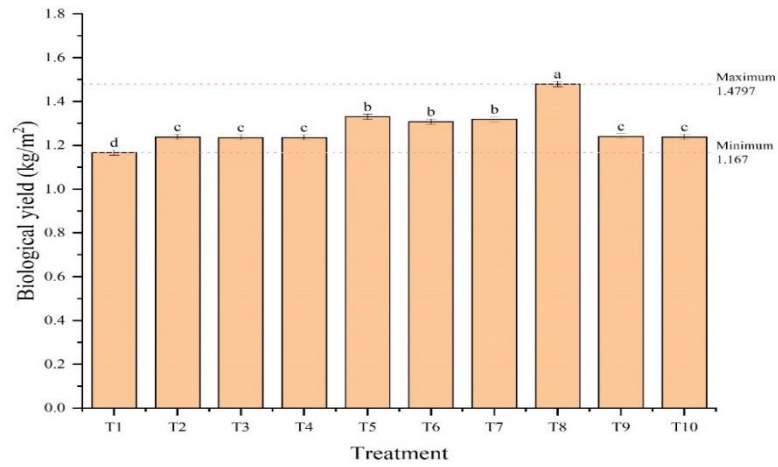


Figure 7: Impact of Biological Yield (kg m⁻²) of wheat in 10 treatments

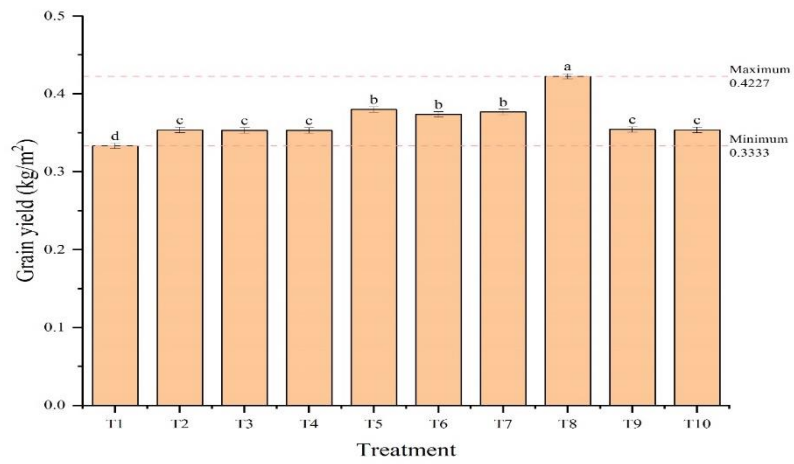


Figure 8: Impact on grain yield (kg m⁻²) of wheat in 10 treatment

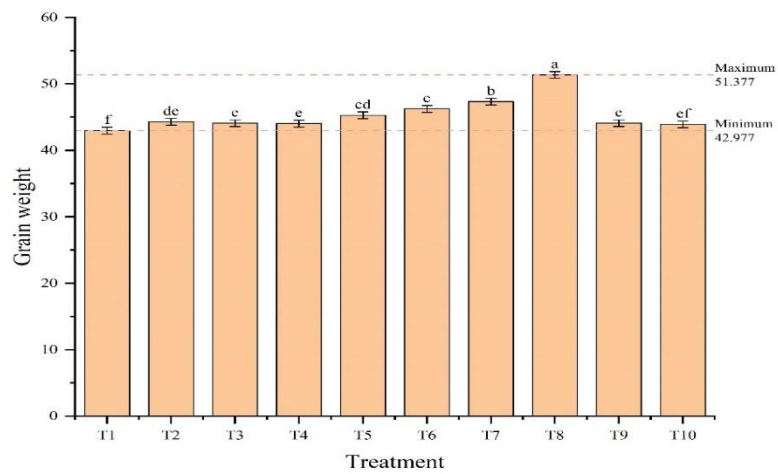


Figure 9: Impact on thousand grain weight (g) of wheat in 10 treatment

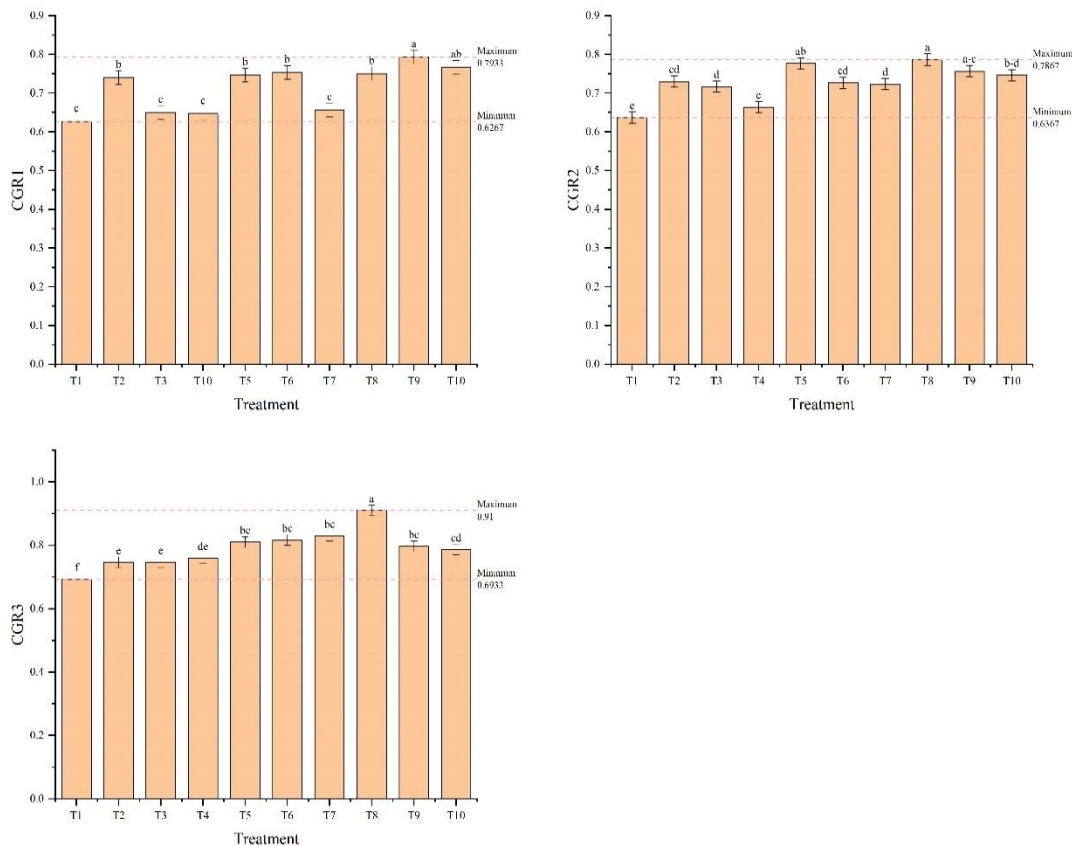


Figure 10: Impact on crop growth rate 1st, 2nd and 3rd (CGR1, CGR2, CGR3)

Overall, the application of Moringa bio-stimulants generally enhanced vegetative development compared to the untreated control (T1). Specifically, foliar application treatments (T2 to T8) consistently resulted in higher mean values for most growth traits, with three sequential sprays of MLE (T8) demonstrating the most significant positive effect. The corresponding data for yield components including Spike Length, Spikelets per Spike, Grains per Spike, 1000-Seed Weight, Biological Yield and Grain Yield, which directly determine the final harvest, are summarized. Similar to the growth traits, the multi-spray MLE treatments significantly outperformed single applications and the seed-treated groups. The most substantial gains were observed in grain

number per spike and 1000-seed weight, confirming the effectiveness of Moringa in improving reproductive success.

4. DISCUSSION

In this study, wheat plants treated with three foliar sprays of moringa leaf extract (MLE) at critical growth stages 40, 75, and 100 days, treatment T8 exhibited the highest plant height (77.50 cm), significantly exceeding control (76.26 cm) and most other treatments (T5, T6, T7). Previously, it is evidenced by a scientist reported 37% increase in shoot biomass when MLE was applied at the tillering stage, leading to taller and more vigorous wheat plants compared to unsprayed controls (Brockman and Brennan, 2017). Similarly, Jahan *et al.*, (2018)

Table 1: Effect of Moringa Treatments on Wheat

Treatments	Plant Height (cm)	No. of Tillers (m ⁻²)	No. of Plants (m ⁻²)	Spike Length (cm)	Spikelets per Spike	Grains per Spike	1000 Seed Weight (g)	Biological Yield (kg m ⁻²)	Grain Yield (kg m ⁻²)
T1	76.333 ^d	152.11 ^d	52.0 ^{cd}	7.833 ^d	11.667 ^f	34.333 ^f	42.977 ^f	1.1670 ^d	0.3333 ^d
T2	76.433 ^{cd}	153.22 ^{a-c}	52.333 ^{b-d}	8.533 ^{b-d}	12.667 ^{d-f}	38.0 ^{de}	44.30 ^{de}	1.2380 ^c	0.3537 ^c
T3	76.533 ^{cd}	152.44 ^{cd}	52.890 ^{a-c}	8.500 ^{b-d}	13.333 ^{b-e}	38.067 ^{de}	44.100 ^e	1.2357 ^c	0.3530 ^c
T4	76.333 ^d	152.56 ^{b-d}	51.443 ^d	8.433 ^{cd}	13.667 ^{b-e}	40.0 ^{cd}	44.050 ^e	1.2357 ^c	0.3530 ^c
T5	77.100 ^{ab}	153.89 ^a	53.777 ^a	9.200 ^{ab}	14.0 ^{b-d}	42.0 ^{bc}	45.283 ^{cd}	1.3300 ^b	0.3800 ^b
T6	76.833 ^{bc}	53.110 ^a	53.110 ^{ab}	9.3000 ^a	14.333 ^{bc}	41.667 ^{bc}	46.260 ^c	1.3080 ^b	0.3737 ^b
T7	76.700 ^{b-d}	53.277 ^{a-c}	53.277 ^{ab}	9.2667 ^a	14.667 ^b	42.500 ^b	47.337 ^b	1.3187 ^b	0.3767 ^b
T8	77.500 ^a	153.67 ^a	53.667 ^a	9.1000 ^a	16.667 ^a	50.0 ^a	51.377 ^a	1.4797 ^a	0.4227 ^a
T9	76.467 ^{cd}	153.59 ^{ab}	53.500 ^a	8.5333 ^{c-f}	13.0 ^{c-f}	36.333 ^{ef}	44.110 ^e	1.2407 ^c	0.3543 ^c
T10	76.400 ^d	153.74 ^a	53.343 ^{ab}	8.4333 ^{ef}	12.333 ^{ef}	35.500 ^f	43.927 ^{ef}	1.2380 ^c	0.3537 ^c

Means within the same column followed by different letters (a, b, c, d, e, f etc) are significantly different at $P \leq 0.05$ according to the LSD All-Pairwise Comparisons Test.

observed that multi-stage foliar applications (tillering, jointing, booting) significantly enhanced morphological traits and biological yield in wheat under field conditions, affirming the importance of repeated foliar MLE application for optimized plant stature. The spike length results further reinforce this: T6 and T7 gave the longest spikes (9.27–9.30 cm), with T8 moderately high (9.10 cm), while the control was markedly lower (7.83 cm). Enhanced spike development through repeated foliar MLE aligns with observations that cytokinin-rich extracts promote assimilate partitioning to the spike, facilitating improved spike morphology and grain-bearing potential (Jahan *et al.*, 2018). Regarding tiller number and plant density, T5, T6, T8, and T10 (seed treatment plus foliar) achieved 153.7 tillers m⁻², and plant density 53.6 plants m⁻² in T5 and T8. The control, by contrast, recorded only 152.1 tillers m⁻² and 52.0 plants m⁻². The

stimulatory impact of MLE on tillering and overall vegetative vigor is well documented: cytokinins (especially zeatin), antioxidants, and amino acids in MLE enhance meristematic activity, leaf initiation, and tiller survival across cereals, as noted by Yasmeen, supported by studies in wheat and rice (Yasmeen *et al.*, 2012, 2013a). The response of spikelets per spike and grain number per spike was especially striking. T5 led with 10.00 spikelets per spike, closely followed by T8 and T9 (9.67), whereas control had only 7.33. Grains per spike were highest in T8 (50), with T7, T5, T6 following (42–41), while control and minimal treatments remained below 37 grains per spike. These increased reproductive components reflect improved sink development, likely due to enhanced nutrient mobilization, hormonal stimulation, and improved assimilate supply derived from foliar MLE as similarly reported by a

scientist with multi-stage MLE sprays significantly improved both spikelet and grain counts in wheat under both optimal and late sowing conditions (Jahan *et al.*, 2018). Yield-related traits followed a consistent pattern: T8 produced the highest 1000-seed weight (51.38 g), biological yield (1.48 kg m⁻²), and grain yield (0.42 kg m⁻²). Two-spray treatments (T5, T6, T7) yielded intermediate gains (1000-seed weight 45.0–45.3 g, grain yield 0.37370.3800 kg m⁻²), while single-spray or seed-only treatments (T2, T3, T4, T9, T10) delivered modest improvements over control. This response is evidenced by a scientist work who found that MLE applied at tillering increased grain yield by 34 %, with single or double sprays also benefiting yield but to a lesser extent. In drought-prone scenarios, a scientist exhibited the research that MLE sprays increased antioxidant activity, chlorophyll content, and ultimately yield under water stress in wheat, underscoring MLE's role in enhancing stress resilience and productivity (Khan *et al.*, 2021).

Crop growth rate (CGR) analysis across three successive 20-day intervals revealed that seed treatment with dry moringa powder (T9) led to the highest early CGR (0.79 g m⁻²/day), slightly outperforming seed extract treatment (T10) and early foliar regimes (T2, T5, T6, T8). However, during mid-season and late-season phases, T8 (triple foliar spray) consistently delivered the highest CGR 0.78 and 0.91 g m⁻²/day, respectively demonstrating its superiority in sustaining growth during grain filling. Seed treatment as a means to boost early vigor is supported by a scientist work, who found that MLE seed treatment improved germination, chlorophyll content, antioxidant enzyme activities, and early seedling growth in wheat under greenhouse conditions (Yasmeen *et al.*, 2012).

In short, seed treatment with dry moringa powder most effectively boosts early crop

vigor (CGR), while optimal growth, morphological trait enhancement, and yield gains are achieved with multiple foliar sprays (especially three-stage T8) of MLE at critical wheat developmental phases. Two-spray regimes (T5, T6, T7) offer a practical compromise with significant benefits, although they consistently underperform compared to the triple-spray protocol. Single-spray or seed-only treatments yield modest improvements but fall short in critical reproductive and yield traits. The gradation of effects in your treatments underscores the importance of application frequency and timing principles echoed in other studies emphasizing growth stage specific benefits of foliar MLE application.

5. CONCLUSION AND RECOMMENDATIONS

The present study highlights the positive influence of *Moringa oleifera* leaf extract and dry powder on the agronomic traits of wheat, with the most significant improvements observed under the treatment involving three foliar applications of leaf extract at 40, 75, and 100 days after sowing. This treatment consistently led to greater plant height and crop growth rate, suggesting that repeated application of moringa extract enhances physiological processes crucial for wheat development.

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