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# EFFECT OF FOLIAR APPLICATION OF MORINGA LEAF EXTRACT (MLE) ON GROWTH, DEVELOPMENT AND YIELD OF MUNGBEAN (*VIGNA RADIATA* L.)

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**A B S T R A C T**

An experiment to study the impact of foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean (*Vigna radiata* L. cv. AEM-96) was carried out at Students' Experimental Farm, Department of Agronomy, Faculty of Crop Production (FCPD), Sindh Agriculture University, Tandojam-Pakistan, during the "Kharif" season, 2023 and the same experiment was repeated during the "Kharif" season, 2024. The field experiment was laid out in four replicated randomized complete block design (RCBD) with a single factor arrangement and seven treatments. The net plot size was 4 m x 3 m (12 $m^2$). The study examines the effect of different concentrations of moringa leaf extract (MLE), MLE @ 20%, 40%, 60%, 80%, and 100% were applied against a control (without MLE) and a recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg $ha^{-1}$) was applied in all plots to evaluate their effects on crop performance. The study aimed to assess, to determine MLE's influence on crop performance, identify the optimal MLE concentration, and analyze correlations and regression relationships among variables. Throughout the experiment, the study aimed to evaluate the measurements included soil physio-chemical properties, agronomic traits, physiological attributes, meteorological observations, grain nutrient status, and economic returns. Statistical analysis was performed using Statistix-8.1 software with the HSD test to compare treatment effects, while the regression and Pearson correlation analysis tested relationships among variables. The results demonstrated that MLE significantly enhanced mungbean performance ($P \leq 0.05$) across both years. The highest response occurred at MLE @ 100%, which recorded the earliest germination (4.5 days compared to 11 days in control) and the highest seed yield SY (1942.87 kg $ha^{-1}$), whereas the control produced the lowest seed yield SY (1386.87 kg $ha^{-1}$). Among, the regression analysis indicated a strong treatment yield relationship ($R^2 = 0.857$, Adjusted $R^2 = 0.807$, $F = 17.17$, $p < 0.0001$), with MLE @ 100% treatment ($T_7$) improving yield by (543.71 kg $ha^{-1}$, $p < 0.0001$), followed by MLE @ 80% treatment ($T_6$) with (453.71 kg $ha^{-1}$). Similarly, Pearson's correlation analysis revealed extremely strong positive relationships between seed yield SY (kg $ha^{-1}$) and traits like (seed weight $pod^{-1}$ SWPP g: r = 0.9979***), (plant height PH cm: r = 0.9971***) and (branches $plant^{-1}$ BPP: r = 0.9937***). Additionally, the results of economic analysis specifically focused on benefit-cost ratio (BCR) showed MLE @ 100% had the highest benefit-cost-ratio (BCR = 3.955), indicating superior profitability. Overall, the study recommends foliar application of MLE @ 100% (200 L $ha^{-1}$) at critical crop growth stages (germination, flowering and pod development), ideally combined with NPK, as an eco-friendly, high-efficiency bio-stimulant for mungbean cultivation.

**Keywords:** Moringa leaf extract (MLE), Growth enhancers, Zeatin, Foliar concentrations, Regression analyses, Pearson's correlation analyses, Growth parameters.

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## INTRODUCTION

Mungbean (*Vigna radiata* L.), also known as green gram; belongs to kingdom plantae of family leguminosae. It is one of the most important grain legume crops in Pakistan due to its vigorous growth even in adverse environment. Mungbean is part of

daily cuisine in the country but its production is low mostly due to imbalance fertilization (Sequeros et al., 2021). It is annually cultivated on an area of 231.1 thousand ha with total production of 204.5 thousand tones in the country (GoP, 2021). As a short-duration crop (55-70 days from sowing to maturity), It can be grown across the seasons in varying cropping systems and crop rotations (Malik, 2016). It is an important food crop worldwide, but especially one of the important pulse crops of Pakistan (Arain, 2012). This crop is one of the most important conventional pulses grown for edible seed which is cooked, fermented, roasted, sprouted or milled. It is a source of high-quality protein for human consumption and can serve as a multipurpose crop, if harvest residues are used as fodder or green manure (Pataczek et al., 2018). Mungbean is becoming important crop as it is the best alternative to meet the food needs of the large population of developing countries due to its, nutritional superiority and nitrogen fixing character (Yi-Shen et al., 2018). Mungbean is particularly attractive for farmers in South Asia because of its short duration and decent performance under adverse climatic conditions such as heat, drought and salinity (Hanumantha Rao et al., Nair, & Nayyar, 2016). Pulses are an important food crop worldwide, especially in South Asia where they are a major source of vegetable proteins and micronutrients including iron for poorer sections of the population (Nair et al., 2013). Moringa (*Moringa oleifera* Lam. Moraceae) is native to tropical, semi-arid, and subtropical areas of the world including sub-Himalayan plains of Pakistan, Bangladesh, Afghanistan and India (Nouman et al., 2012). Moringa is a highly prized plant grown primarily for obtaining the moringa flowers, leaves, roots, seed, pods, and gum which all are utilized for food, medicine, and industry. Moringa leaf extract (MLE) is a natural remedy that includes bioactive ingredients and eco-friendly organic fertilizer. Moringa leaf extract (MLE) is a natural bio-stimulant and eco-friendly organic fertilizer, rich in phytohormones and growth-promoting compounds. It contains essential macro and micronutrients (N, P, K, Ca, B, Mg, Cu, Zn, Mn, Na, and Fe), making it highly effective in enhancing plant growth and productivity (Trigo et al., 2021). Moringa is a highly profitable plant that grows wild and is grown in many locations across the world. It is a rustic multipurpose tree that grows sporadically along the region's roadside and is popular for usage as a vegetable in our country. Moringa is extremely appreciated plant with versatile properties, according to several studies. Moringa leaf cutting is used as an organic fertilizer either through a foliar application in small doses or a soil applied to help crops grow well and produce more yield. Moringa foliage extract (MFE) contains a high concentration of synthetic hormones, notably vitamins, minerals, essential amino acids, antioxidants including vitamin C, and beta-carotene, which has been demonstrated to increase agricultural yield by 10-45%. Moringa juice comprises micronutrients in sufficient amounts and proportions to improve physiological development, crop yield, and produce of a variability of crops, ranging from mueslis to vegetables. *Moringa oleifera* is a highly adoptable plant to our ecological conditions and grown by the farmers for using its flowers as a food (vegetable). The leaves are used as a feed for the animals while the branches and stem are rich source of fuel for home consumptions. There is no regular cultivation of *Moringa oleifera* trees but farmers grow it on water channels only for their domestic use. The farmers who have large number of trees on their farms collect the flowers by hiring the labors and market them as high value vegetable. The extract of *Moringa oleifera* leaves contain 80% ethanol and enhance about 20-35% yield of various cereals (Hoque et al., 2020).

## MATERIALS AND METHODS

A field experiment was conducted at Students' Experimental Farm, Department of Agronomy, Faculty of Crop Production (FCPD), Sindh Agriculture University, Tandojam- Pakistan which is located at '25 ° 60N 68 ° 3160E', approximately 19 km from the city of Hyderabad (Sindh), along with Hyderabad and Mirpurkhas Road. The experiment was conducted during the "Kharif" season, 2023 and the same experiment was repeated during the "Kharif" season, 2024, to study the effect of foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean (*Vigna radiata* L.). The field experiment was laid out in four replicated randomized complete block design (RCBD) with a single factor arrangement and seven treatments. The net plot size was 4 m x 3 m (12 $m^2$). In this experiment, mungbean variety 'Atomic Energy Mungbean-96 (AEM-96)' was tested consistently across all experimental plots in both years to evaluate its performance under identical agronomic conditions, and the same procedure was followed during both years of field study. Seed rate @ (20 kg $ha^{-1}$) was used with the help of single coulter row hand drill in respective plots during the "Kharif" season 1$^{st}$ week of March 6, 2023-2024. The row to row spacing 20 cm and plant to plant spacing 15 cm was maintained after thinning. The fertilizer source of Nitrogen was Urea, Phosphorus in the form of Di-ammonium Phosphate (DAP) and Potassium as Sulphate of Potash. Nitrogen and Phosphorus were applied at recommended dose fertilizer (RDF) NPK of 25-50-25 (kg

$ha^{-1}$) in the form of Urea and DAP. Total DAP and 1/2 Urea was applied at the time of land preparation while remaining Urea was applied at the time of 2nd irrigation respectively. Fresh moringa leaves were collected from Students' Experimental Farm, and grinned with some quantity of distilled water by using juicer blender to get fresh moringa leaf extract (MLE) and applied on mungbean crop as foliar spray. The treatment details are as under: The treatments included were $T_1$: Control (without MLE), $T_2$: Recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg $ha^{-1}$), $T_3$: MLE @ 20%, $T_4$: MLE @ 40%, $T_5$: MLE @ 60%, $T_6$: MLE @ 80% and $T_7$: MLE @ 100%. Throughout the experiment, the study aimed to evaluate the impact of soil physio-chemical properties: i.e. (soil texture, electrical conductivity (EC $dSm^{-1}$), organic matter (OM %), total nitrogen (N %), available phosphorus (P mg $kg^{-1}$) and extractable potassium (K mg $kg^{-1}$), agronomic traits such as: days to first seed germination (DFSG), plant height (PH cm), branches $plant^{-1}$ (BPP), pods $plant^{-1}$ (PPP), seeds $pod^{-1}$ (SPP), seed weight $pod^{-1}$ (SWPP g), seed index (SI-1000-seed wt; g), biological yield (BY kg $ha^{-1}$), seed yield (SY kg $ha^{-1}$), harvest index (HI %) and protein content (PC %) from grains. Meanwhile, physiological responses such as: total dry matter (TDM kg $ha^{-1}$), leaf area index (LAI), leaf area duration (LAD $day^{-1}$), crop growth rate (CGR, $gm^{-2}$ $day^{-1}$), net assimilation rate (NAR, g $m^{-2}$ $day^{-1}$) and leaf stem ratio (LSR g $m^{-2}$ $day^{-1}$). Notably, meteorological observations such as: minimum temperature ($^0$C), maximum temperature ($^0$C), relative humidity (%) and rainfall (mm). Additionally, nutrients analysis from mungbean grains such as: chemical analysis of *Moringa oleifera* leaf extract: and economic feasibility such as: benefit-cost-ratio (BCR) for mungbean cultivation under the influence of moringa leaf extract (MLE) application. For statistical validation, all collected data were analyzed using Statistix-8.1 software with the HSD test to compare treatment effects. The present study investigated the effect of foliar application of moringa leaf extract (MLE) on growth, development, yield and quality of mungbean (*Vigna radiata* L.) under the agro-climatic conditions of Tandojam, Sindh-Pakistan.

**Method and preparation of moringa leaf extracts (MLE)**

One kilogram (1kg) of fresh *Moringa oleifera* leaves were collected from Students' Experimental Farm, Department of Agronomy, Faculty of Crop Production (FCPD), Sindh Agriculture University, Tandojam-Pakistan. Fresh *Moringa oleifera* green leaves were grinned with some quantity of distilled water by using a conventional electric mixer (10000 rpm) juicer blender to get fresh moringa leaf extract (MLE) and applied on mungbean crop as foliar spray. In case then mixed with 1liter ethyl alcohol (80% aq.) using a blender. The extract will be purified by filtering twice through (Whatman no. I) filter paper. After purification the extract were subjected to a rotary evaporator to fully evaporate the alcohol and get the crude extract. The mixture was passed through a cloth sieve (mesh) to separate the juice from the residue. The juice was collected into 500-ml flask. The different concentrations were prepared from the crude extract 20, 40 and 60 ml from the crude extract was taken and diluted with 980 ml, 960 ml and 940 ml distilled water for reaching the concentration to 2%, 4% and 6% respectively according to (Bashir et al., 2014). Seven different concentrations were prepared per-hectare ($ha^{-1}$) spray doses use this in the field of mungbean crop as follow: These seven different concentrations in addition to the control (without MLE) was sprayed on grain legume mungbean (*Vigna radiata* L.) grain crop at a rate of 3 ml, 6 ml, 9 ml, 12 ml and 15 ml $plant^{-1}$ at an interval of two weeks following emergence. The MLE were applied as per respective treatment after first irrigation on foliar application as per treatments. The extract of MLE was prepared properly. Spraying was done early in the morning to take advantage. Let's break down and interpret the key components and aspects of the table: The data (Table. 1) evaluated that it summarizes the per-hectare spray doses of different concentrations of moringa leaf extract (MLE) used in field experiment during 2023 and 2024 on mungbean crop. The table simplifies preparation by fixing spray volume at 200 L $ha^{-1}$, which is a standard field spray volume for mungbean crop. Farmers and researchers can directly mix MLE and water in calculated ratios without further conversions. The data (Table. 1) suggested that a fixed spray volume of 200 L $ha^{-1}$ was used, and treatment levels were established as control (without MLE), recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg $ha^{-1}$), and five concentrations of MLE (20%, 40%, 60%, 80% and 100%). The calculation for each treatment is based on the formula:

MLE (L $ha^{-1}$) = (C / 100) × V

Water (L $ha^{-1}$) = V – MLE

where C is the target concentration (%) and V = 200 L $ha^{-1}$ (total spray solution). The detail of treatments is as under:

$T_1$ (Control): no MLE applied; only 200 L $ha^{-1}$ tap water.

$T_2$ (RDF-NPK): recommended dose of NPK @ 25: 50: 25 (kg $ha^{-1}$) applied; no MLE spray.

$T_3$ (MLE 20%): 40 L $ha^{-1}$ MLE + 160 L $ha^{-1}$ tap water.

$T_4$ (MLE 40%): 80 L $ha^{-1}$ MLE + 120 L $ha^{-1}$ tap water.

$T_5$ (MLE 60%): 120 L $ha^{-1}$ MLE + 80 L $ha^{-1}$ tap water.

$T_6$ (MLE 80%): 160 L ha$^{-1}$ MLE + 40 L ha$^{-1}$ tap water.
$T_7$ (MLE 100%): 200 L ha$^{-1}$ pure MLE (no water dilution).
Thus, the table provides clear, calculation-ready guidelines for preparing MLE treatments, establishing a gradient from 20% to 100% to identify the optimal concentration for mungbean growth and yield. It ensures consistency across two years while comparing MLE bio-stimulant effects with conventional RDF (NPK) fertilizer, offering an eco-friendly alternative to chemical inputs.

**Useful small-scale mixes (for farmers who spray with smaller tanks)**

**Per 100 L spray mix (easy for many tractors/sprayers)**

MLE @ 20% → 20 L MLE + 80 L water
MLE @ 40% → 40 L MLE + 60 L water
MLE @ 60% → 60 L MLE + 40 L water
MLE @ 80% → 80 L MLE + 20 L water
MLE @ 100% → 100 L MLE + 0 L water

**Knapsack (15 L) equivalents-quick farmer conversions (common handheld sprayer):**

MLE @ 20% → 0.20 × 15 = 3.0 L MLE + 12.0 L water
MLE @ 40% → 0.40 × 15 = 6.0 L MLE + 9.0 L water
MLE @ 60% → 0.60 × 15 = 9.0 L MLE + 6.0 L water
MLE @ 80% → 0.80 × 15 = 12.0 L MLE + 3.0 L water
MLE @ 100% → 15.0 L MLE (no water)

Table 1: Per-hectare (ha$^{-1}$) spray doses use this in the field of mungbean crop as here's a clear, calculation-ready way to express each treatment's dose per hectare, different concentrations foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean (year-I-2023) and (year-II-2024), both years of study, table used for field experiment.

| Treatment concentrations | Target % (v/v) | Volume by volume (V/V) given mix | MLE (Liters per hectare L ha$^{-1}$) | Water (Liters per hectare L ha$^{-1}$) |
|---|---|---|---|---|
| $T_1$ = Control | 0 % | No MLE applied | 0 | 200 |
| $T_2$ = RDF NPK | — | NPK @ 25: 50: 25 (kg ha$^{-1}$) | — | — |
| $T_3$ = MLE @ 20 % | 20 % | (3 ml MLE + 15 ml water) three ml of juice (MLE) mixed with 15 ml of tap water (3 :15 by volume) - (3 + 15) | 3/15 x 200 = 40 | 160 |
| $T_4$ = MLE @ 40 % | 40 % | (6 ml MLE + 15 ml water) six ml of juice (MLE) mixed with 15 ml of tap water (6 :15 by volume) - (6 + 15) | 6/15 x 200 = 80 | 120 |
| $T_5$ = MLE @ 60 % | 60 % | (9 ml MLE + 15 ml water) nine ml of juice (MLE) mixed with 15 ml of tap water (9 :15 by volume) - (9 + 15) | 9/15 x 200 = 120 | 80 |
| $T_6$ = MLE @ 80 % | 80 % | (12 ml MLE + 15 ml water) twelve ml of juice (MLE) mixed with 15 ml of tap water (12 :15 by volume) - (12 + 15) | 12/15 x 200 = 160 | 40 |
| $T_7$ = MLE @ 100 % | 100 % | (15 ml MLE + 15 ml water) fifteen ml of juice (MLE) mixed with 15 ml of tap water standard solution (100 %) (15 :15 by volume) - (15 +15) | 15/15 x 200 = 200 | 20 |

Detail of Table:
Let V = spray volume (L ha$^{-1}$) you plan to apply.
For a target C % (v/v) MLE: MLE (L ha$^{-1}$) = (C/100) × V; Water (L ha$^{-1}$) = V − MLE
If you use a common spray volume of 200 L ha$^{-1}$, the per-hectare mixes are:
Note: The treatment $T_1$ (control, no MLE) & treatment $T_2$ apply fertilizer at NPK @ 25: 50: 25 (kg ha$^{-1}$) (no MLE in this treatment).

**Chemical analysis of inorganic minerals**

**Inorganic minerals**

Mineral elements were extracted from plant tissues following the procedure as suggested by Chapman & Pratt (1961). Phosphorus (P) following Humphries (1956), Potassium (K) through photometric method following Williams and Twine (1961), Calcium (Ca) and Magnesium (Mg) through atomic absorption spectrophotometer following AOAC (1984) and Total nitrogen (N) by Microkejeldhal, Tector model 1026 after digestion in sulphuric acid (Horwiz, 2002) were determined.

**Nutrients analysis**

**Chemical analysis of Moringa oleifera leaf extract**

Chemicals content in moringa leaf extract (MLE) the nutrients "macro and micronutrients" contained in moringa leaf extract (MLE) which was applied for enhancing the growth, development, yield components, and yield positive results in a grain legume mungbean crop. Makkar (2007) found that the juice from fresh moringa leaves can be used to produce an effective plant growth hormone, increasing yields by 25-30% for a number of crops such as mungbean, soyabean, maize, and coffee. It was later discovered that it was actually zeatin that is a natural plant hormone and belongs to the cytokinin group, involved in increasing the yield of crops. It was suggested that zeatin foliar spray should be applied along with other fertilizers, making it clear that this hormone cannot serve in place of fertilizers but if applied along with other fertilizers produce better

results. With this experiment, importance of moringa leaf juice as a natural plant growth promoter came into light.

**Analytical results of *moringa oleifera* leaf extract (macro & micronutrients two consecutive years of study (year-I-2023) and (year-II-2024)**

The data (Table 2) evaluated those analytical results of the *Moringa oleifera* leaf extract, with both macro and micronutrient content in two trial years (2023 and 2024) using a reliable 400°C digestion method. Results indicate year-to-year fluctuations in nutrient levels. Here are a breakdown and discussion of the results: The data of the parameters analyzed from the Department of Soil & Environmental Sciences Division (S&ES-Division) Nuclear Institute of Agriculture (NIA), Tandojam (Hyderabad), Sindh-Pakistan.

For macronutrients, the total nitrogen (N) content and total phosphorus (P) levels slightly decreased from 2023 to 2024, while water-soluble phosphorus and total potassium (K) increased, suggesting improved phosphorus availability and overall potassium content despite a drop in water-soluble potassium. Similarly, the micronutrients zinc (Zn) and manganese (Mn) showed notable increases in 2024, potentially benefiting enzymatic activity and photosynthesis, whereas iron (Fe) declined slightly, possibly affecting chlorophyll synthesis. In last copper (Cu) in 2023 and 2024, below detection limit (BDL), indicating that the absence of detectable copper indicates a deficiency of this micronutrient, which could affect various physiological functions. Overall, nutrient trends reflect mixed changes in soil fertility, with some improvements in availability but potential concerns regarding copper (Cu) and iron (Fe) levels.

Table 2: Analytical results of *moringa oleifera* leaf extract macro and micronutrients table used for field experiment, two consecutive years of study (year-I-2023) and (year-II-2024).

| (Year-I-2023) | | (Year-II-2024) | |
|---|---|---|---|
| Macronutrients | Amount ppm | Macronutrients | Amount ppm |
| Chemical Analysis of Moringa Oleifera Leaf Extract | | | |
| Total nitrogen (N %) | 0.065 | Total nitrogen (N %) | 0.061 |
| Total phosphorus (P) | 101.8 | Total phosphorus (P) | 98.8 |
| Water-soluble phosphorus (P) | 30.3 | Water-soluble phosphorus (P) | 34.5 |
| Total potassium (K) | 340 | Total potassium (K) | 402 |
| Water-soluble potassium (K) | 420 | Water-soluble potassium (K) | 380 |
| Digestion method Temp: 400 °C | | | |
| Micronutrients | Amount ppm | Micronutrients | Amount ppm |
| Zinc (Zn) | 1.13 | Zinc (Zn) | 1.27 |
| Iron (Fe) | 30.44 | Iron (Fe) | 28.65 |
| Manganese (Mn) | 0.62 | Manganese (Mn) | 1.01 |
| Copper (Cu) | BDL = below detection limit | Copper (Cu) | BDL = below detection limit |

Source: Soil & Environmental Sciences Division, Nuclear Institute of Agriculture (NIA), Tandojam (Sindh).

**High-performance liquid chromatography (HPLC) analytical results of moringa *oleifera* leaf extract phytochemical (Zeatin) two consecutive years of study (year- I-2023) and (year-II-2024)**

The data (Table 3) presents the analytical results of high-performance liquid chromatography (HPLC) for *Moringa oleifera* leaf extract (MLE), focusing on phytochemical content across two different years, 2023 and 2024. The data of the parameters analyzed from sourced Pakistan Council of Scientific & Industrial Research (PCSIR) Laboratories Complex Peshawar (KP. K)-Pakistan, ensuring a level of credibility and scientific rigor. Let's break down and interpret the key components and aspects of the table. Here's an analysis and discussion of the data. The primary phytochemical highlighted is Zeatin, from a cytokinin group that plays a crucial role in plant growth and development. The amount of Zeatin measured in 2023 was (94.36 mmole/ml), significantly higher than the (18.6 mmole/ml) recorded in 2024.

This stark decline could indicate variations in environmental factors, extraction methods, or the plant's growth conditions. Both years recorded similar environmental conditions with a temperature of 23 °C and humidity of 58%. This suggests that the significant change in Zeatin levels is likely due to factors other than immediate environmental conditions, perhaps involving the specific cultivation practices or harvest timing. The statement of compliance notes the use

of foliar spray of *Moringa oleifera* leaf extracts to enhance the content of not only Zeatin but also other compounds like Stevioside and various minerals in Stevia rebaudiana. This method could impact the phytochemical profile significantly, indicating the importance of methodological consistency in such studies.

Table 3: High-performance liquid chromatography (HPLC) analytical results of *moringa oleifera* leaf extract (MLE) two consecutive years of study (year-I-2023) and (year-II-2024).

| Parameters | (Year-I-2023) | | (Year-II-2024) | |
|---|---|---|---|---|
| | Phytochemical | Amount mmole/ml | Phytochemical | Amount mmole/ml |
| | Environmental Conditions Temp: 23 °C and Humidity 58 (°C) | | | |
| Moringa Oleifera Leaf Extract | Zeatin | 94.36 | Zeatin | 18.6 |
| Method Used/Statement of Compliance | Foliar Spray of *Moringa Oleifera* Lam. Leaf extracts (MLE) enhance the Stevioside, Zeatin and mineral content in Stevia rebaudiana Betoni. South African Journal of Botany. Volume 132, August 2020. Page 249-257. | | | |

Source: Pakistan Council of Scientific & Industrial Research (PCSIR) Laboratories Complex Peshawar (KP. K).

**Soil sampling and analysis two consecutive years of study (year-I-2023) and (year-II-2024)**

Soil from the experimental area was analyzed before-sowing and after-harvesting. Soil samples were taken with the help of a soil auger at a depth of 0-15 cm from five different locations of the total experimental area before sowing of the crop. The soil samples were air-dried, ground, sieved (2 mm) and placed in plastic containers. The samples were analyzed for various physical and chemical properties by procedures of Ryan et al., (2001). The soil texture was measured by the Bouyoucos Hydrometer method by Bouyoucos (1962). Electrical conductivity (EC $dSm^{-1}$) was measured by digital conductivity meter, diagnosis and improvement of saline and alkali soils and soil pH were measured by digital pH meter, respectively. Walkely-Black (1958) method was followed for the determination of organic matter content. Total nitrogen (N %) was calculated by the Kjeldahl method using a standard procedure (Horwitz, 1980). AB-DTPA methods (HLS. Tondon, 2005) was used to measure the extractable phosphorus and potassium. The Physico-chemical properties such as Sand (%), Silt (%), Clay (%), Electrical conductivity (EC $dSm^{-1}$), soil pH and organic matter (OM %) of the soil for all experiments are given in the data (Table. 4). Here's a breakdown and discussion of the results: The data (Table. 4) evaluated the soil analysis across two growing seasons (2023 and 2024), highlighting stable alkaline pH, slight shifts in electrical conductivity (EC $dSm^{-1}$), and gradual improvements in organic matter and nitrogen, indicating better soil fertility. However, phosphorus depletion and varying potassium levels highlight the need for balanced nutrient management in future cropping cycles.

**Agro-climatic conditions**

The weather data related to minimum and maximum temperature (°C), relative humidity (%) and rainfall (mm) were collected from Meteorological Observatory Station, AGRO-MET, Tandojam, Sindh-Pakistan. Tandojam with subtropical climate has four distinct seasons: spring, winter, summer and Autum. Winter starts from the middle of October to the end of March. December and January are the coldest months, with an average temperature of around 13°C and 15°C, respectively. The lowest temperatures recorded in a single day is 2 and 0.5 degrees Celsius, respectively. Summer starts from Ist April and goes to the end of July, with an average temperature of 39.5 ° C in May and 38.4 ° C in June, and extreme highs of 46 °C and 46.5 °C, respectively. From late June to mid-October, the monsoon season prevails. During the growing season of both years, the temperature remained at 17.1 °C in March and 24.3 °C in May. Meteorological data are presented in data (Table. 5 & Fig. 1a to 1b). It is evident from data analysis of agro-meteorological data (Table. 5 & Fig. 1a to 1b) presents agro-meteorological data for mungbean crops in Tandojam (Sindh) for the months of March, April, and May in the years 2023 and 2024. The data include weekly measurements of minimum and maximum temperature (in °C), relative humidity (in %), and rainfall (in mm). Let's break down and interpret the key aspects of the table. The data (Table. 5 & Fig. 1a to 1b) evaluated that the temperatures increased from March to May in both years, with 2024 recording higher peaks, especially in late May (up to 49.75°C). Relative humidity was generally high in March for both seasons but declined toward May, indicating drier conditions, particularly in 2024. Rainfall remained low in both years, with slightly more precipitation in 2023, while 2024 experienced only trace amounts.

Table 4: Physico-chemical properties of the soil of field experiments, two consecutive years of study (year-I-2023) and (year-II-2024).

| | (Year-I-2023) | | (Year-II-2024) | |
|---|---|---|---|---|
| Parameters | Before sowing | After harvesting | Before sowing | After harvesting |
| | Soil texture analysis | | | |
| Sand (%) | 22.6 | - | 22.6 | - |
| Silt (%) | 52.4 | - | 52.4 | - |
| Clay (%) | 32.8 | - | 32.8 | - |
| Texture class | Silty loam | - | Silty loam | - |
| | Soil physico-chemical analysis | | | |
| Electrical conductivity (EC $dSm^{-1}$) | 0.44 | 0.47 | 0.58 | 0.36 |
| Soil pH | 8.45 | 8.37 | 8.45 | 8.31 |
| Organic matters (OM %) | 0.47 | 0.58 | 0.74 | 0.77 |
| Total nitrogen (N %) | 0.03 | 0.036 | 0.046 | 0.048 |
| Extractable phosphorus (P mg $kg^{-1}$) | 6.25 | 7.75 | 7.25 | 6.16 |
| Extractable potassium (K mg $kg^{-1}$) | 89.5 | 107.5 | 109.2 | 105.83 |

Source: Farm Advisory Center, Fauji Fertilizer Company Limited (FFC), Hyderabad-Sindh-Pakistan.

Table 5: Agro-meteorological data of Tandojam two consecutive years of study (year-I-2023) and (year-II-2024).

| Months | Week | (Year-I-2023) | | | | | (Year-II-2024) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature °C | | | Relative Humidity (%) | Rainfall (mm) | Temperature °C | | | Relative Humidity (%) | Rainfall (mm) |
| | | Min. | Max. | Mean Temp. | | | Min | Max: | Mean Temp. | | |
| March | i | 14.5 | 37 | 33 | 90 | 0 | 6.5 | 32 | 22.5 | 86 | 4.4 |
| | ii | 15 | 37.5 | 33.75 | 85 | 0 | 10 | 33.5 | 26.75 | 85 | 0 |
| | iii | 16 | 35 | 33.5 | 90 | 2 | 11.5 | 37.5 | 30.25 | 72 | 0 |
| | iv | 16 | 36.5 | 34.25 | 91 | 1 | 17.5 | 40 | 37.5 | 81 | 0 |
| Aprail | i | 17 | 36.5 | 35.25 | 83 | 0 | 19 | 38.5 | 38.25 | 87 | 0 |
| | ii | 19 | 40 | 39 | 87 | 0 | 18.5 | 41 | 39 | 83 | Trace |
| | iii | 19 | 40 | 39 | 92 | 0 | 19.5 | 36.5 | 37.75 | 87 | 3 |
| | iv | 18 | 39.5 | 37.75 | 91 | 13 | 21.5 | 39.5 | 41.25 | 73 | 0 |
| May | i | 19 | 39 | 38.5 | 68 | 0 | 19 | 43 | 40.5 | 88 | 0 |
| | ii | 22.5 | 45 | 45 | 84 | 0 | 23 | 44 | 45 | 86 | 0 |
| | iii | 24.5 | 43.5 | 46.25 | 88 | 0 | 25 | 45 | 47.5 | 84 | 0 |
| | iv | 23 | 42 | 44 | 85 | 5 | 26 | 47.5 | 49.75 | 81 | 0 |

Source: Meteorological Observatory Station, AGRO-MET, Tandojam, Sindh-Pakistan.

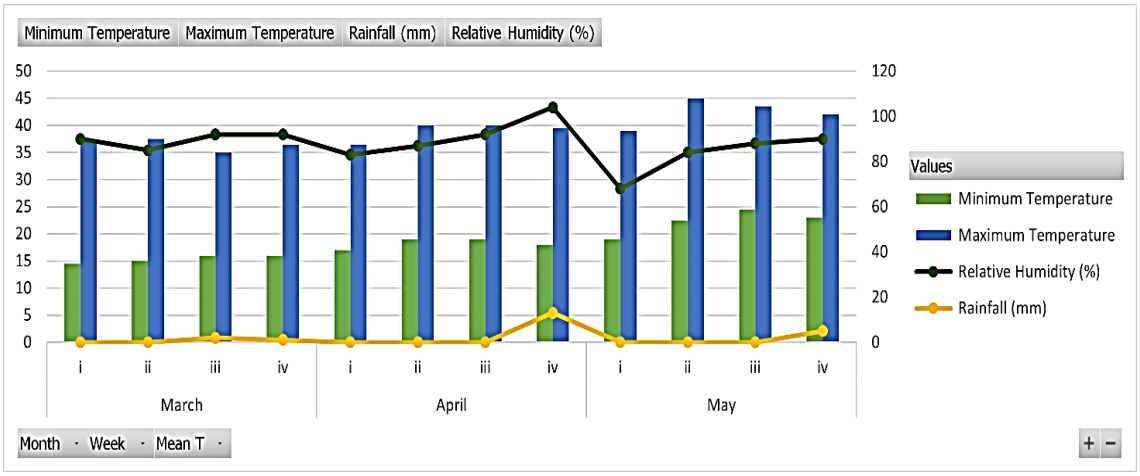



Figure 1(a): Meteorological data of Tandojam (year-I-2023).

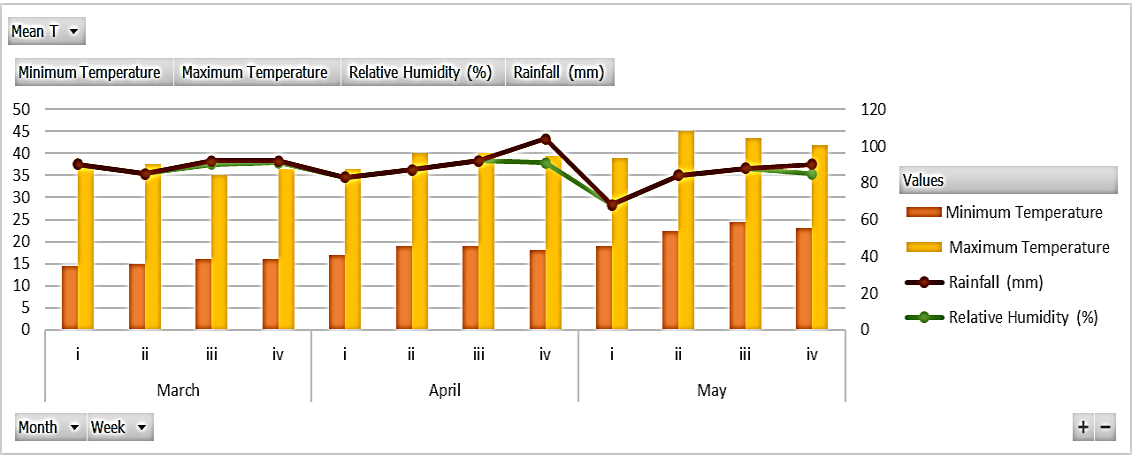



Figure 1(b): Meteorological data of Tandojam (year-II-2024).

## RESULTS AND DISCUSSION

### Field Experiment

A field experiment was conducted during "Kharif" season, 2023 and 2024 on the mungbean crop. The key findings of this experiment and their interpretations are presented below.

**Effect of foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean (*Vigna radiata* L.)**

The results of field experiment are presented in data (Tables 6 to 10.b). The data recorded on various aspects were tabulated and subjected to statistical analysis. The research results pertaining to each aspect have been presented and described along with statistical inferences under the following heads. The results of field studies and their interpretations are presented below.

**Agronomic observations**

**Days to first seed germination (DFSG)**

The data (Table 6) evaluated that days to first seed germination (DFSG) in mungbean were significantly affected ($P \leq 0.05$) by different MLE concentrations. Higher MLE levels consistently reduced germination time, compared to the control (11 days) and RDF (NPK) treatment $T_2$, (10.5 days). The fastest germination (4.5 days) occurred at 100 % MLE, confirming that increasing MLE concentration accelerates early seed germination.

**Plant height (PH cm)**

The data (Table 6) suggested that different foliar applications of Moringa Leaf Extract (MLE) positively affect the plant height (cm) of mungbean ($P \leq 0.05$). Plant height (cm) of mungbean increased significantly with higher concentrations of Moringa Leaf Extract (MLE), with a strong statistical effect ($P = 0.0000$). The maximum plant height (87.58 cm) was recorded at MLE @ 100 % treatment $T_7$, and plant height (cm) decreased gradually with lower MLE levels. Similarly, control and RDF (NPK) treatments showed the lowest plant heights (cm), confirming a clear dose-dependent growth response to MLE.

**Branches plant$^{-1}$ (BPP)**

The data (Table 6) investigates the effect of foliar application of moringa leaf extract (MLE) on the number of branches plant$^{-1}$ in mungbean crop. Analysis of variance (ANOVA) revealed a highly significant ($P = 0.0000$, $P \leq 0.05$) positive effect of foliar application of moringa leaf extract (MLE) on mungbean branches plant$^{-1}$, with increasing concentrations enhancing branches plant$^{-1}$. The highest branches plant$^{-1}$ (14.6125) were observed at 100 % MLE treatment $T_7$, decreasing branches plant$^{-1}$ to 7.2375 in the untreated control treatment $T_1$, while RDF (NPK) treatment $T_2$ yielded (8.9875 branches plant$^{-1}$). Overall, our findings indicate that MLE outperforms RDF (NPK) treatment and control group, though with diminishing returns at higher concentrations.

**Pods plant$^{-1}$ (PPP)**

The data (Table 6) suggested that different foliar applications of moringa leaf extract (MLE) positively and significantly increased the pods plant$^{-1}$ of mungbean ($P \leq 0.05$), showing a clear dose-dependent response. The highest pods plant$^{-1}$ count was recorded in MLE @100 % (78 pods), while the control treatment $T_1$, produced the lowest (33.17 pods plant$^{-1}$).

**Seeds pod$^{-1}$ (SPP)**

The data (Table 6) suggested that analysis of variance (ANOVA) results showed a significantly increase in seeds pod$^{-1}$ with different concentrations of MLE compared to the control and even the recommended dose of fertilizer (RDF) NPK ($P \leq 0.05$). The highest seeds pod$^{-1}$ count (13.92) was observed in 100 % MLE treatment ($T_7$), followed by progressively lower counts with reduced MLE

concentrations treatment ($T_6$ to $T_3$). The control treatment ($T_1$) had the lowest seeds pod$^{-1}$ count (7.73), confirming MLE's positive dose-dependent effect on seed production.

**Seed weight pod$^{-1}$ (SWPP g)**

The data (Table. 6) suggested that analysis of variance (ANOVA) values revealed that MLE foliar applications significantly increased seed weight pod$^{-1}$ (g) in mungbean ($P \leq 0.05$). The highest seed weight pod$^{-1}$ (0.45 g) was recorded at MLE @ 100 % treatment $T_7$, with values gradually decreasing as MLE concentration decreased. Similarly, control group (without MLE) treatment $T_1$ had the lowest seed weight pod$^{-1}$ (0.34 g), confirming that both MLE doses and RDF (NPK) significantly influenced seed weight pod$^{-1}$ (g) in mungbean crop.

**Seed index (SI-1000-seed wt; g)**

The data (Table 6) suggested that analysis of variance (ANOVA) results showed that seed index (SI-1000-seed wt; g) of mungbean was significantly improved by foliar applications of moringa leaf extract (MLE) at ($P \leq 0.05$). The highest seed index (SI-1000-seed wt; 58.75 g) was recorded with MLE @ 100 % treatment $T_7$, with seed index (SI-1000-seed wt; g) decreasing gradually as MLE concentration declined. All MLE treatments performed better than the control, while RDF (NPK) fertilizer improved seed index (SI-1000-seed wt; g) slightly but remained lower than MLE treatments of 40 % and above.

**Biological yield (BY kg ha$^{-1}$)**

The data table (Table. 6) evaluated that analysis of variance (ANOVA) results showed that MLE foliar applications had a highly significant effect on biological yield BY (kg ha$^{-1}$) of mungbean ($P \leq 0.05$). The highest biological yield BY (7104.75 kg ha$^{-1}$) was obtained with MLE @ 100 % treatment $T_7$, with yield decreasing gradually at lower MLE concentrations. Similarly, the lowest biological yield BY of, (4175 kg ha$^{-1}$), was recorded in the control group (without MLE) treatment $T_1$ highlighting the baseline performance without MLE or synthetic fertilizer, which did not receive any foliar treatment or additional fertilizer, highlighting the importance of external supplementation with MLE to improve plant productivity. Overall, the study confirming that the superior effectiveness of MLE in enhancing biological yield BY (kg ha$^{-1}$) of mungbean crop.

**Seed yield (SY kg ha$^{-1}$)**

The data (Table 6) evaluated that analysis of variance (ANOVA) values revealed that the foliar application of moringa leaf extract (MLE) subjected to different treatments in field trials had a significantly increased mungbean seed yield SY (kg ha$^{-1}$) in a concentration-dependent manner, with the highest seed yield SY (1942.87 kg ha$^{-1}$) at MLE @ 100 % treatment $T_7$. All MLE treatments ($T_3$–$T_7$) outperformed both the recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha$^{-1}$) treatment $T_2$ (1536.75 kg ha$^{-1}$) and the control group (without MLE) treatment $T_1$, (1386.87 kg ha$^{-1}$). The results indicate that MLE's superior efficacy over conventional fertilizer alone, with yield consistently declining as MLE concentration decreased.

**Harvest index (HI %)**

The data (Table. 6) evaluated that analysis of variance (ANOVA) results showed that foliar application of MLE significantly increased the harvest index (HI %) of mungbean, with a highly significant (P-value: 0.0000, $P \leq 0.05$). Higher MLE concentrations produced higher harvest index (HI %), with the maximum harvest index (HI) of (41.49 %) recorded at MLE @ 100 % treatment $T_7$, followed by progressively lower values at reduced concentrations. All MLE treatments outperformed both the fertilizer-alone treatment and the control group (without MLE) treatment $T_1$, which recorded the lowest harvest index (HI) of (30.45 %).

**Protein content (PC %) from grains**

The data (Table. 6) evaluated that analysis of variance (ANOVA) values revealed that the foliar application of Moringa Leaf Extract (MLE) subjected to different treatments in field trials had a significantly positive effect on the protein content (PC %) from grains of mungbean ($P \leq 0.05$), with the highest protein content (PC) level (23.38 %) observed at MLE @ 100 % treatment $T_7$. Protein content (PC %) from grains of mungbean decreased progressively with lower MLE concentrations but remained higher than both the recommended dose of fertilizer (RDF) NPK treatment $T_2$ (15.74 %) and the control group treatment $T_1$ (without MLE) (13.56 %). The results suggested that MLE is an effective bio-stimulant for enhancing protein content (PC %) from grains of mungbean, outperforming conventional fertilizer and no treatment.

**Physiological parameters (Field experiment)**

**Total dry matter (TDM kg ha$^{-1}$)**

The data (Table 6) evaluated that analysis of variance (ANOVA) results revealed that the foliar application of moringa leaf extract (MLE) subjected to different treatments in field trials had a significant effect on the total dry matter (TDM kg ha$^{-1}$) of mungbean plants ($P \leq 0.05$), with the highest total dry matter (TDM) (7231.75 kg ha$^{-1}$) recorded at MLE @ 100 % treatment $T_7$, showing a strong dose-dependent response. Similarly, the control group treatment $T_1$ (without MLE), which received no foliar treatment or additional fertilizer, had the lowest total dry matter (TDM) of (3547.87 kg ha$^{-1}$), All MLE treatments outperformed but RDF (NPK) treatment $T_2$

and control group treatment $T_1$ (without MLE), having the lowest total dry matter (TDM kg $ha^{-1}$), confirming the superior effectiveness of MLE in enhancing biomass.

**Leaf area index (LAI)**

**(a). $LAI_1$ $m^{-2}$ (21 DAS)**

The data (Table 7a) evaluated that analysis of variance (ANOVA) results showed that foliar application of MLE had a highly significant positive effect on leaf area index [$LAI_1$ $m^{-2}$ (21 DAS)] of mungbean (0.0000, $P \leq 0.05$). The highest leaf area index ($LAI_1$ 21 DAS) of (0.290 $m^{-2}$) was observed in plants treated with MLE @ 100 % treatment $T_7$, and values gradually decreased with lower MLE concentrations. Similarly, the control group (without MLE) treatment $T_1$, which did not receive any foliar treatment or additional fertilizer, recorded the lowest leaf area index ($LAI_1$ 21 DAS) of (0.214 $m^{-2}$), highlighting the importance of supplementary treatments in promoting leaf expansion and overall plant growth, while RDF (NPK) fertilizer improved leaf area index [$LAI_1$ $m^{-2}$ (21 DAS)] but remained less effective than higher MLE doses.

**Leaf area index (LAI)**

**(b). $LAI_2$ $m^{-2}$ (52 DAS)**

The data (Table 7b) evaluated that analysis of variance (ANOVA) results ($P = 0.0000$, $P \leq 0.05$) confirmed the highly significant positive effect on the leaf area index [$LAI_2$ $m^{-2}$ (52 DAS)] of mungbean plants on leaf development. The highest leaf area index [$LAI_2$ (52 DAS)] of (0.982 $m^{-2}$) was observed in plants treated with MLE @ 100 % treatment $T_7$. As the concentration of MLE decreased, a corresponding decrease in the leaf area index [$LAI_2$ $m^{-2}$ (52 DAS)] was observed. Similarly, the recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg $ha^{-1}$) treatment $T_2$ led to a leaf area index [$LAI_2$ (52 DAS)] of (0.909 $m^{-2}$), while the control group (without MLE) treatment $T_1$, which received no foliar applications on treatment or additional fertilizer, exhibited the lowest leaf area index [$LAI_2$ (52 DAS)] of (0.884 $m^{-2}$) respectively.

**Leaf area duration (LAD, $days^{-1}$)**

The data (Table 7) evaluated that analysis of variance (ANOVA) results showed that foliar application of MLE significantly increased leaf area duration (LAD $days^{-1}$) in mungbean ($P \leq 0.05$). The highest leaf area duration (LAD) of (24.20 $days^{-1}$) was recorded in plants treated with MLE @ 100 % treatment $T_7$, with values gradually decreasing as MLE concentration declined. All MLE treatments performed better than RDF (NPK) treatment $T_2$ and the control group (without MLE) treatment $T_1$, which did not receive any foliar treatment or additional fertilizer, had the lowest leaf area duration (LAD) of (14.99 $days^{-1}$) respectively.

**Crop growth rate (CGR, $gm^{-2}$ $day^{-1}$)**

The data (Table 7) evaluated that analysis of variance (ANOVA) results showed that foliar application of Moringa Leaf Extract (MLE) significantly increased the crop growth rate (CGR, $gm^{-2}$ $day^{-1}$) of mungbean ($P \leq 0.05$). The highest crop growth rate (CGR) of (95.72 $gm^{-2}$ $day^{-1}$) was observed in plants treated with MLE @ 100 % treatment $T_7$, indicating that this full concentration of MLE was the most effective in promoting rapid plant growth. As the concentration of MLE decreased, a corresponding decline in the crop growth rate (CGR, $gm^{-2}$ $day^{-1}$) was observed. Similarly, the control group (without MLE) treatment $T_1$, which did not receive any foliar treatment or additional fertilizer, had the lowest crop growth rate (CGR) of (52.74 $gm^{-2}$ $day^{-1}$), All MLE treatments outperformed RDF (NPK) and control, which showed the lowest crop growth rate (CGR, $gm^{-2}$ $day^{-1}$).

**Net assimilation rate (NAR, g $m^{-2}$ $day^{-1}$)**

The data (Table. 7) evaluated that analysis of variance (ANOVA) results showed a highly significant ($P \leq 0.05$) positive effect of Moringa Leaf Extract (MLE) foliar application on the net assimilation rate (NAR, g $m^{-2}$ $day^{-1}$) of mungbean, with the highest net assimilation rate (NAR) of (185.691 g $m^{-2}$ $day^{-1}$) was observed in plants treated with MLE @ 100 % treatment $T_7$, indicating that this full concentration of MLE was the most effective in enhancing photosynthetic efficiency and biomass accumulation. Net assimilation rate (NAR, g $m^{-2}$ $day^{-1}$) decreased progressively with lower MLE concentrations, and the control group (without MLE) treatment $T_1$, which did not receive any foliar treatment or additional fertilizer, exhibited the lowest a net assimilation rate (NAR) of (128.95 g $m^{-2}$ $day^{-1}$), indicating MLE's effectiveness over standard fertilizer or no treatment.

**Leaf stem ratio (LSR g $m^{-2}$ $day^{-1}$)**

**(a). LSR (21 DAS)**

The data (Table. 7a) evaluated that analysis of variance (ANOVA) results showed that foliar application of MLE significantly increased the leaf stem ratio (LSR 21 DAS g $m^{-2}$ $day^{-1}$) of mungbean plants ($P \leq 0.05$), with higher MLE concentrations producing stronger effects. The highest leaf stem ratio (LSR 21 DAS) of (1.79 g $m^{-2}$ $day^{-1}$) was observed in plants treated with MLE @ 100 % treatment $T_7$, while values gradually decreased with lower MLE levels. Similarly, the control group (without MLE) treatment $T_1$, which received no foliar treatment or additional fertilizer, had the lowest leaf stem ratio (LSR 21 DAS) of (1.41 g $m^{-2}$ $day^{-1}$), underscoring the importance of supplemental treatments to optimize leaf and stem growth.

Table 6: Agronomic & physiological parameters means & standard error (S.E) of field experiment as effected by foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean (*Vigna radiata* L.) (P-value of 0.0000, P ≤ 0.05, HSD 5%).

| Treatments | Agronomic Traits | | | | | | | | | | | Physiological Traits |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DFSG | PH (cm) | BPP | PPP | SPP | SWPP (g) | SI (1000-seed wt; g) | BY (kg ha$^{-1}$) | SY (kg ha$^{-1}$) | HI (%) | PC (%) | TDM (kg ha$^{-1}$) |
| | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E |
| $T_1$ | 11 ± 0.35$^{a}$ | 46.6 ± 1.48$^{f}$ | 7.2375 ± 0.27$^{e}$ | 33.17 ± 2.10$^{f}$ | 7.73 ± 0.209$^{f}$ | 0.34 ± 0.007$^{f}$ | 45 ± 1.275$^{e}$ | 4175 ± 129.301$^{e}$ | 1386.87 ± 30.624$^{e}$ | 30.45 ± 0.303$^{f}$ | 13.56 ± 0.504$^{f}$ | 3547.87 ± 59.571$^{e}$ |
| $T_2$ | 10.5 ± 0.25$^{a}$ | 54.38 ± 2.034$^{e}$ | 8.9875 ± 0.14$^{d}$ | 42.87 ± 1.91$^{e}$ | 9.21 ± 0.060$^{e}$ | 0.37 ± 0.007$^{e}$ | 49.37 ± 1.081$^{d}$ | 4785 ± 183.49$^{de}$ | 1536.75 ± 36.068$^{d}$ | 33.98 ± 0.478$^{e}$ | 15.74 ± 0.314$^{e}$ | 4561.75 ± 162.91$^{d}$ |
| $T_3$ | 9.25 ± 0.21$^{b}$ | 60.97 ± 1.69$^{de}$ | 10.12 ± 0.24$^{d}$ | 46.57 ± 4.41$^{de}$ | 10.12 ± 0.129$^{d}$ | 0.39 ± 0.006$^{de}$ | 51.75 ± 1.13$^{cd}$ | 5400 ± 250.00$^{cd}$ | 1607.5 ± 45.258$^{cd}$ | 35.67 ± 0.671$^{d}$ | 17.34 ± 0.314$^{d}$ | 5507.87 ± 294.31$^{c}$ |
| $T_4$ | 8 ± 0.354$^{c}$ | 65.91 ± 1.96$^{cd}$ | 11.43 ± 0.38$^{c}$ | 52.85 ± 4.71$^{cd}$ | 11.16 ± 0.192$^{c}$ | 0.40 ± 0.004$^{cd}$ | 54 ± 0.93$^{bc}$ | 5845 ± 167.388$^{c}$ | 1667.87 ± 30.84$^{bc}$ | 36.64 ± 0.63$^{cd}$ | 18.86 ± 0.226$^{c}$ | 5241.87 ± 242.53$^{c}$ |
| $T_5$ | 7 ± 0.354$^{cd}$ | 72.66 ± 2.27$^{bc}$ | 12.57 ± 0.31$^{c}$ | 61.52 ± 4.67$^{bc}$ | 11.95 ± 0.19$^{b}$ | 0.41 ± 0.002$^{c}$ | 55.75 ± 0.545$^{b}$ | 6137 ± 141.93$^{bc}$ | 1744.12 ± 35.720$^{b}$ | 37.77 ± 0.570$^{c}$ | 20.22 ± 0.289$^{b}$ | 6195.75 ± 256.39$^{b}$ |
| $T_6$ | 6 ± 0.35$^{d}$ | 78.55 ± 2.71$^{b}$ | 13.46 ± 0.32$^{ab}$ | 68.56 ± 5.14$^{b}$ | 12.67 ± 0.23$^{b}$ | 0.43 ± 0.003$^{b}$ | 56.75 ± 0.54$^{ab}$ | 6810 ± 294.66$^{ab}$ | 1852.87 ± 39.165$^{a}$ | 49.44 ± 0.616$^{b}$ | 22.45 ± 0.121$^{a}$ | 6799.62 ± 185.14$^{a}$ |
| $T_7$ | 4.5 ± 0.250$^{e}$ | 87.58 ± 2.32$^{a}$ | 14.61 ± 0.21$^{a}$ | 78 ± 4.03$^{a}$ | 13.92 ± 0.15$^{a}$ | 0.45 ± 0.006$^{a}$ | 58.75 ± 0.650$^{a}$ | 7104.7 ± 179.9$^{a}$ | 1942.87 ± 31.973$^{a}$ | 41.49 ± 0.751$^{a}$ | 23.38 ± 0.299$^{a}$ | 7231.75 ± 172.69$^{a}$ |

Table 7: Physiological parameters means & standard error (S.E) of field experiment as effected by foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean (*Vigna radiata* L.) (P-value of 0.0000, P ≤ 0.05, HSD 5%).

| Treatments | Physiological Traits | | | | | | |
|---|---|---|---|---|---|---|---|
| | $LAI_1$ m$^{-2}$ 21 DAS | $LAI_2$ m$^{-2}$ 52 DAS | LAD, (days$^{-1}$) | CGR (gm$^{-2}$ day$^{-1}$) | NAR (g m$^{-2}$ day$^{-1}$) | LSR 21 DAS (g m$^{-2}$ day$^{-1}$) | LSR 52 DAS (g m$^{-2}$ day$^{-1}$) |
| | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E | Means ± S. E |
| $T_1$ | 0.214 ± 0.006$^{f}$ | 0.884 ± 0.003$^{f}$ | 14.99 ± 0.407$^{f}$ | 52.74 ± 1.649$^{f}$ | 128.95 ± 1.330$^{f}$ | 1.41 ± 0.057$^{f}$ | 2.52 ± 0.025$^{f}$ |
| $T_2$ | 0.233 ± 0.007$^{e}$ | 0.909 ± 0.003$^{e}$ | 16.80 ± 0.488$^{e}$ | 63.26 ± 1.883e | 137.81 ± 1.152$^{ef}$ | 1.48 ± 0.067$^{ef}$ | 2.60 ± 0.032$^{e}$ |
| $T_3$ | 0.245 ± 0.006$^{d}$ | 0.924 ± 0.003$^{d}$ | 17.67 ± 0.372$^{de}$ | 74.67 ± 1.523$^{d}$ | 145.39 ± 1.346$^{de}$ | 1.54 ± 0.081$^{de}$ | 2.67 ± 0.027$^{d}$ |
| $T_4$ | 0.257 ± 0.006$^{c}$ | 0.943 ± 0.002$^{c}$ | 19.15 ± 0.391$^{d}$ | 81.31 ± 1.431$^{c}$ | 154.39 ± 1.889$^{cd}$ | 1.60 ± 0.091$^{cd}$ | 2.73 ± 0.023$^{c}$ |
| $T_5$ | 0.270 ± 0.005$^{b}$ | 0.955 ± 0.003$^{bc}$ | 20.72 ± 0.447$^{c}$ | 86.75 ± 1.275$^{b}$ | 164.31 ± 3.205$^{bc}$ | 1.67 ± 0.094$^{bc}$ | 2.79 ± 0.026$^{c}$ |
| $T_6$ | 0.279 ± 0.004$^{b}$ | 0.965 ± 0.002$^{b}$ | 22.26 ± 0.612$^{b}$ | 91.62 ± 0.802$^{a}$ | 176.49 ± 4.336$^{ab}$ | 1.73 ± 0.085$^{ab}$ | 2.86 ± 0.019$^{b}$ |
| $T_7$ | 0.290 ± 0.004$^{a}$ | 0.982 ± 0.003$^{a}$ | 24.20 ± 1.045$^{a}$ | 95.72 ± 1.227$^{a}$ | 185.691 ± 4.695$^{a}$ | 1.79 ± 0.077$^{a}$ | 2.94 ± 0.019$^{a}$ |

Note: Summary and detail of treatments

$T_1$ = Control (without MLE); $T_2$ = Recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha$^{-1}$); $T_3$ = MLE @ 20 %; $T_4$ = MLE @ 40 %; $T_5$ = MLE @ 60 %; $T_6$ = MLE @ 80 %; $T_7$ = MLE @ 100 %

**Leaf stem ratio (LSR g $m^{-2}$ $day^{-1}$)**

**(b). LSR (52 DAS)**

The data (Table. 7b) evaluated that analysis of variance (ANOVA) values indicating that the foliar application of Moringa Leaf Extract (MLE) significantly improved the leaf stem ratio (LSR 52 DAS g $m^{-2}$ $day^{-1}$) of mungbean plants ($P \leq 0.05$), with the highest leaf stem ratio (LSR 52 DAS) of (2.94 g $m^{-2}$ $day^{-1}$), was observed in plants treated with MLE @ 100 % treatment $T_7$. The leaf stem ratio (LSR 52 DAS g $m^{-2}$ $day^{-1}$) decreased progressively with lower MLE concentrations, and the control group (without MLE) treatment $T_1$, which did not receive any foliar treatment or additional fertilizer, had the lowest leaf stem ratio (LSR 52 DAS) of (2.52 g $m^{-2}$ $day^{-1}$), confirming MLE's positive and dose-dependent effect on plant growth.

**Statistical analysis (correlation and regression)**

**Regression analysis (Field experiment)**

The data (Table. 8 & Fig. 2a to 2b) presents the results of an Ordinary Least Squares (OLS) regression model results analysis, analyzing the effect of foliar application of moringa leaf extract (MLE) and imposed MLE applied treatments and recommended dose of fertilizer (RDF) NPK on the seed yield SY (kg $ha^{-1}$) of mungbean.

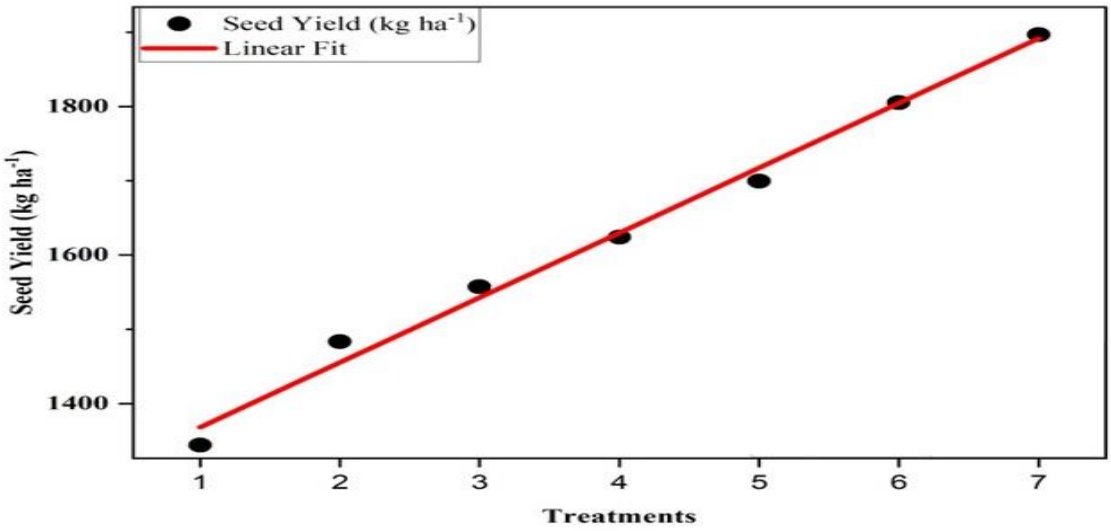



Figure 2(a): Linear regression analysis among seed yield (kg $ha^{-1}$) and imposed MLE applied treatments effect of foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean.

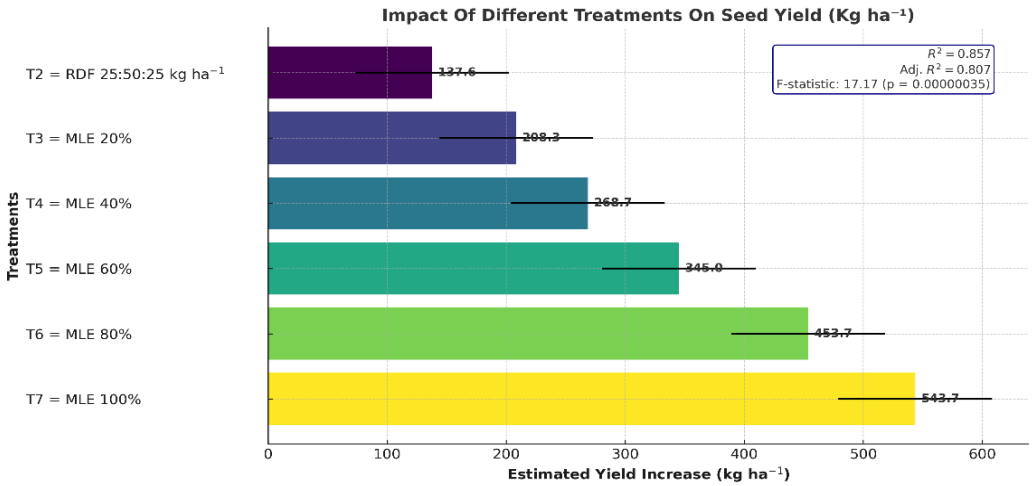



Figure 2(b): Bar plot representation illustrates the impact of foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean, on seed yield (kg $ha^{-1}$), and shows key insights into how each treatment influences yield relative to a baseline (control) during the field experimental season both years of study 2023 and 2024.

Table 8: Regression analysis among the seed yield (kg ha$^{-1}$) and imposed MLE applied treatments effect of foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean, during the field experimental season both years of study 2023 and 2024.

OLS Regression Results Model Summary

| | | | |
|---|---|---|---|
| Dep. Variable: | Seed yield (SY kg ha$^{-1}$) | R-squared: | 0.857 |
| Model: | OLS | Adj. R-squared: | 0.807 |
| Method: | Least Squares | F-statistic: | 17.17 |
| Date: | Fri, 06 June, 2025 | Prob (F-statistic): | 0.000000351 |
| Time: | 17:11:33 PM | Log-Likelihood: | -153.12 |
| No. Observations: | 28 | AIC: | 334.6 |
| Df Residuals: | 20 | BIC: | 344.9 |
| Df Model: | 7 | | |
| Covariance Type: | non-robust | | |

Coefficient Analysis (Treatments vs Control):

| Factors | Coeff | Std. Err | t-value | p-value | 95% CI (Lower) | 95% CI (Upper) |
|---|---|---|---|---|---|---|
| Intercept (Baseline: Control) | 1399.17 | 48.87 | 28.63 | 0.0 | 1297.22 | 1501.11 |
| $T_2$ = RDF @ 25: 50: 25 (kg ha$^{-1}$) | 137.68 | 64.65 | 2.13 | 0.046 | 2.72 | 272.45 |
| $T_3$ = MLE @ 20% | 208.33 | 64.65 | 3.22 | 0.004 | 73.47 | 343.2 |
| $T_4$ = MLE @ 40% | 268.71 | 64.65 | 4.16 | 0.0 | 133.85 | 403.57 |
| $T_5$ = MLE @ 60% | 345.96 | 64.65 | 5.34 | 0.0 | 210.1 | 479.82 |
| $T_6$ = MLE @ 80% | 453.71 | 64.65 | 7.02 | 0.0 | 318.85 | 588.57 |
| $T_7$ = MLE @ 100% | 543.71 | 64.65 | 8.41 | 0.0 | 408.85 | 678.57 |
| $T_1$ = Control (without MLE) | -49.17 | 97.75 | -0.5 | 0.62 | -253.06 | 154.73 |

| | | | |
|---|---|---|---|
| Omnibus: | 0.886 | Durbin-Watson: | 3.477 |
| Prob (Omnibus): | 0.642 | Jarque-Bera (JB): | 0.244 |
| Skew: | 0.204 | Prob (JB): | 0.885 |
| Kurtosis: | 3.206 | Cond. No. | 21.7 |

The regression analysis showed that foliar application of MLE had a highly significant effect on mungbean seed yield (kg ha$^{-1}$), with the model explaining 85.7% of yield variability (R-squared ($R^2$) = 0.857; Adj. R-squared = 0.807; $p < 0.0001$), emphasizing which is very high, indicating a strong relationship between MLE treatments and seed yield (kg ha$^{-1}$), and an Adjusted R-squared of 0.807, can be explained by the treatments and factors included in the model fits the data is overall well. The results highlight that the highest seed yield (543.71 kg ha$^{-1}$, $p < 0.0001$) was achieved with MLE @ 100 % treatment $T_7$, showing the strongest and most significant positive effect, followed by MLE @ 80 % treatment $T_6$ seed yield of (453.71 kg ha$^{-1}$, $p < 0.0001$), with progressively smaller but still highly significant gains at lower MLE concentrations. In addition, recommended dose of fertilizer (RDF) NPK treatment $T_2$ supplementation also positively impacts on seed yield with an estimated escalation of (137.68 kg ha$^{-1}$, $p < 0.0001$), but was far less effective than any MLE treatment. Overall, the results confirm that foliar application of MLE especially at higher concentrations significantly boosts mungbean seed yield (kg ha$^{-1}$), with no major multicollinearity or replication effects in the model. These findings confirm MLE as a potent, natural growth enhancer for mungbean, with efficacy rising alongside concentration.

**Correlation analysis (Field experiment)**

Pearson correlation analysis the data (Table 9) presents the correlation matrix for various variables agronomic and physiological traits, which were measured in field experiment, and conducted in two consecutive years of study 2023 and 2024. Pearson correlation analysis results values, evaluated that our findings of current results revealed a strong positive relationship among key agronomic traits in mungbean plants (all $r > 0.99$, $p < 0.001$). The results evaluated that the traits move together and have high mutual influence that a Pearsons's correlation analysis showed that (seed yield SY kg $ha^{-1}$) is strongly positively correlations with seed weight $pod^{-1}$ SWPP (g): r = 0.9979***), (seeds $pod^{-1}$ SPP: r = 0.9954***), (branches $plant^{-1}$ BBP: r = 0.9937***), (plant height PH cm: r = 0.9971***), (protein content from grains PC %: r = 0.9959***), (leaf stem ratio LSR 52 DAS g $m^{-2}$ $day^{-1}$: r = 0.9968***), (leaf area index $LAI_1$ 21 DAS: r = 0.9943***) indicating that taller plants tend to have more branches, produce more pods, yield higher, and sustain larger leaf areas over time. Similarly, photosynthetic indicators (net assimilation rate NAR, g $m^{-2}$ $day^{-1}$, crop growth rate CGR, $gm^{-2}$ $day^{-1}$) also showed strong positive correlations with yield traits. Overall, this experiment underscores the impact of MLE treatments on interconnected growth and yield parameters, reinforcing that multiple foliar sprays MLE @ 100 % treatment $T_7$, can improve mungbean productivity.

Table 9: Correlation analysis showed positive and negative interactions among studied traits under different imposed (MLE) applied treatments effected by foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean during the field experimental season both years of study 2023 and 2024.

| | *DFSG* | *PH* | *BPP* | *PPP* | *SPP* | *SWPP* | *SI* | *BY* | *SY* | *HI* | *PC* | *TDM* | *LAI 21DAS* | *LAI52DAS* | *LAD* | *CGR* | *NAR* | *LSR21DAS* | *LSR52DAS* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***DFSG*** | 1 | | | | | | | | | | | | | | | | | | |
| ***PH*** | 0.9941324 | 1 | | | | | | | | | | | | | | | | | |
| ***BPP*** | 0.9944489 | 0.9951494 | 1 | | | | | | | | | | | | | | | | |
| ***PPP*** | 0.9905218 | 0.9966252 | 0.989432 | 1 | | | | | | | | | | | | | | | |
| ***SPP*** | 0.9918208 | 0.9974729 | 0.9986571 | 0.9914497 | 1 | | | | | | | | | | | | | | |
| ***SWPP*** | 0.9886483 | 0.9936593 | 0.9925261 | 0.9875673 | 0.9951006 | 1 | | | | | | | | | | | | | |
| ***SI*** | 0.9802373 | 0.9810161 | 0.9925509 | 0.9683881 | 0.9908752 | 0.9888516 | 1 | | | | | | | | | | | | |
| ***BY*** | 0.996503 | 0.9923645 | 0.995247 | 0.9850413 | 0.9937985 | 0.9911028 | 0.9853531 | 1 | | | | | | | | | | | |
| ***SY*** | 0.9943618 | 0.9971272 | 0.9936514 | 0.9942883 | 0.9953736 | 0.9979391 | 0.9826213 | 0.993945 | 1 | | | | | | | | | | |
| ***HI*** | 0.9845423 | 0.9905078 | 0.9898242 | 0.9811857 | 0.9930472 | 0.9990412 | 0.9904254 | 0.9883746 | 0.9947783 | 1 | | | | | | | | | |
| ***PC*** | 0.9983534 | 0.9939444 | 0.9958814 | 0.9906319 | 0.993873 | 0.9913716 | 0.9827289 | 0.9986303 | 0.9958885 | 0.9868876 | 1 | | | | | | | | |
| ***TDM*** | 0.9869428 | 0.9813544 | 0.9774855 | 0.9726287 | 0.9765958 | 0.9840543 | 0.9732678 | 0.9800022 | 0.9851425 | 0.9847262 | 0.9804698 | 1 | | | | | | | |
| ***LAI 21DAS*** | 0.9949473 | 0.994717 | 0.9997935 | 0.9886918 | 0.9981348 | 0.9933247 | 0.9935925 | 0.9950784 | 0.994038 | 0.9909706 | 0.9958155 | 0.9807341 | 1 | | | | | | |
| ***LAI52DAS*** | 0.9891039 | 0.9921761 | 0.9988662 | 0.9844304 | 0.9983918 | 0.9926041 | 0.9954828 | 0.9932137 | 0.99114 | 0.9910365 | 0.9924219 | 0.9717741 | 0.9984538 | 1 | | | | | |
| ***LAD*** | 0.9908915 | 0.9969796 | 0.9903609 | 0.9995838 | 0.9924027 | 0.9868954 | 0.9686725 | 0.9870338 | 0.993887 | 0.9804599 | 0.9917443 | 0.9698187 | 0.9891665 | 0.9857911 | 1 | | | | |
| ***CGR*** | 0.9842083 | 0.9783596 | 0.9912435 | 0.9632198 | 0.9872517 | 0.9817285 | 0.995659 | 0.9897142 | 0.9784001 | 0.9831628 | 0.9851107 | 0.9740481 | 0.9920605 | 0.9924492 | 0.9650403 | 1 | | | |
| ***NAR*** | 0.9939859 | 0.9945515 | 0.9889812 | 0.9969276 | 0.9890452 | 0.9823695 | 0.9644902 | 0.9898999 | 0.9917705 | 0.9751247 | 0.9941704 | 0.9702091 | 0.9877571 | 0.9828707 | 0.9980974 | 0.9661517 | 1 | | |
| ***LSR21DAS*** | 0.9965251 | 0.9979267 | 0.9964977 | 0.9963014 | 0.9961255 | 0.9885433 | 0.9793412 | 0.993963 | 0.9943809 | 0.9835654 | 0.9965011 | 0.9762704 | 0.9956796 | 0.9924301 | 0.997358 | 0.9798756 | 0.9975474 | 1 | |
| ***LSR52DAS*** | 0.9960414 | 0.998525 | 0.9966989 | 0.9950898 | 0.9975296 | 0.9925672 | 0.9818768 | 0.9965653 | 0.9967789 | 0.9885643 | 0.9975786 | 0.9773812 | 0.995872 | 0.9940163 | 0.9964999 | 0.9819571 | 0.9963232 | 0.9989569 | 1 |

Note: "*** = Highly significant at 5% ($p \leq 0.05\%$) probability level", or "Significant at 99% confidence level," 0.90-0.99 ***, 0.71-0.89**, 0.61-0.70*"

**Economical analysis (Field experiment, two consecutive years of study 2023 and 2024)**

**(a). Benefit-cost-ratio (BCR)**

The data (Table. 10.a) presents the benefit-cost-ratio (BCR) of mungbean two consecutive years of field study (2023–2024) found that foliar application of moringa leaf extract (MLE) significantly improved mungbean yield and economic returns. The findings revealed a clear trend: as the concentration of MLE increased, there was a consistent improvement in crop yield, gross income (Rs. $ha^{-1}$), net income (Rs. $ha^{-1}$), and ultimately the benefit-cost-ratio (BCR). Nevertheless, the highest benefit-cost-ratio (BCR) of (3.955) is observed with MLE @ 100 % concentration treatment $T_7$, yielding (1,942.87 kg $ha^{-1}$), and the highest gross income of (Rs. 362,898.4 $ha^{-1}$), and a net income of (Rs. 271,208.06 $ha^{-1}$). Economic analysis showed a clear positive trend: higher MLE concentrations consistently increased gross and net income, outperforming both the control (without MLE) treatment ($T_1$) benefit-cost-ratio of (BCR 2.705) emphasizing meaning the return is (Rs. 2.705 for every Rs. 1 spent). Similarly, the recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg $ha^{-1}$) treatment $T_2$ shows a benefit-cost-ratio (BCR) of (3.02), indicating a slight improvement, with a total cost of production ($ha^{-1}$) the total expenditure incurred in this field experiment was (Rs. 112,190.64 $ha^{-1}$). Overall, moringa leaf extract (MLE) especially at full strength proves to be a cost-effective, eco-friendly bio-stimulant that enhances both productivity and profitability in mungbean farming.

**(b). Cost of production ($ha^{-1}$)**

The data (Table. 10.b) demonstrated that the total cost of production per hectare ($ha^{-1}$) was (Rs. 112,190.64 $ha^{-1}$), for mungbean (*Vigna radiata* L.) cultivation under field experiment conducted in 2023 and 2024, where moringa leaf extract (MLE) was applied as a foliar bio-stimulant at varying concentrations, with major expenses including land rent (Rs. 18,000), fertilizers (Urea, DAP, SOP totaling Rs. 57,980), seed (Rs. 9,500), tillage (Rs. 5,000), irrigation (Rs. 4,560.64), harvesting (Rs. 6,000), and crop management (Rs. 3,500). Moringa leaf extract (MLE) was applied as a foliar bio-stimulant, contributing to the overall management costs.

## DISCUSSION

The field experiment conducted during 2023–2024 evaluated the influence of foliar application of Moringa Leaf Extract (MLE) on the growth, development, physiology, yield and seed nutritional quality of mungbean (*Vigna radiata* L.). The results of both years combined study 2023-2024 (field experiment) are presented in the data (Tables. 6 to 7). The data recorded on various aspects were tabulated and subjected to statistical analysis. The research results pertaining to each aspect have been presented and described along with statistical inferences under the following heads. The results of field studies and their discussions are presented below for this experiment so, this discussion includes detailed descriptions and statistical interpretations for each agronomic and physiological parameter analyzed. The findings consistently demonstrated that MLE, particularly at 100 % concentration treatment $T_7$, significantly enhanced agronomic and physiological traits, aligning with and extending prior scientific evidence on MLE's role as a natural bio-stimulant. Below is a consolidated summary of the key findings: In this study, I investigated the effects of different doses of Moringa Leaf Extract (MLE) on mungbean growth, biochemical properties, yield, and seed nutritional content.

The results revealed that foliar application of MLE significantly enhanced the studied attributes, particularly growth parameters such as leaf area index (LAI), crop growth rate (CGR, $gm^{-2}$ $day^{-1}$), net assimilation rate (NAR, g $m^{-2}$ $day^{-1}$), leaf stem ratio LSR (g $m^{-2}$ $day^{-1}$) and seedling root and shoot length. The most notable improvements were observed with a MLE @ 100 % application treatment $T_7$. The increase in productivity and growth is attributed to MLE's bioactive compounds, including zeatin, cytokinin's, vitamins, and antioxidants, which promote: early germination, enhanced root and shoot growth, better branching, improved photosynthesis (via higher LAI and LAD) and higher seed quality and protein content PC %. The observed growth boost can be attributed to the blend of nutrients, amino acids, antioxidants, and cytokinin's in Moringa Leaf Extract (MLE), which function as bio-stimulants (Sadak et al., 2024). Previous research (Irshad et al., 2024) has shown that foliar application of Moringa Leaf Extract (MLE) increases plant hormones, which promote seedling growth by mobilizing metabolites to the growing plumule. Foliar application of Moringa Leaf Extract (MLE) has been reported to enhance growth in various crops, including soybean (Irshad et al., 2024), mungbean (Anwar et al., 2023), wheat (Yasmeen et al., 2012), maize (Hafeez et al., 2022), and sorghum (Ahmad et al., 2016). Similarly, (Rashid et al., 2021) studies have highlighted that exogenous bio-stimulants can effectively boost crop growth and yield. Moringa Leaf Extract (MLE) application at different growth stages of crops like soybean, mungbean, and wheat has been shown to improve seedling growth

metrics such as weight, root length, and shoot length (Irshad et al., 2024). Leaf area and leaf area index (LAI) plays a critical role in crop yield, serving as the main site for converting water and carbon dioxide into carbohydrates during photosynthesis (Zhu et al., 2010). The increase in leaf area observed in this study can be attributed to the growth hormones and nutrients present in Moringa Leaf Extract (MLE), particularly potassium (K) (Brockman et al., 2020). Moringa Leaf Extract (MLE) also stimulates the early production of bioactive compounds, delaying leaf senescence and promoting more leaf area with higher photosynthetic pigments (Farooq et al., 2023).

Table 10(a): Benefit-cost-ratio (BCR) of mungbean as affected by different concentrations foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean (*Vigna radiata* L.)., two consecutive years of study (2023 and 2024), table used for field experiment.

| Treatment concentrations | Yield ($kgha^{-1}$) | Income from Grains (Rs. $ha^{-1}$) | Income from Straw (Rs. $ha^{-1}$) | Gross Income (Rs. $ha^{-1}$) | Total Expenditure (Rs. $ha^{-1}$) | Net Income (Rs. $ha^{-1}$) | (BCR) |
|---|---|---|---|---|---|---|---|
| Field Experiment | | | | | | | |
| Effect of foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean *(Vigna radiata L.)*. | | | | | | | |
| $T_1$ = Control (without MLE) | 1386.875 | 214752.5 | 33400.125 | 248152.65 | 91690.31 | 156462.315 | 2.705 |
| $T_2$ = RDF-NPK @ 25: 50: 25 (kg $ha^{-1}$) | 1536.75 | 237930 | 38932.25 | 276862.25 | 91690.31 | 185171.94 | 3.02 |
| $T_3$ = MLE @ 20 % | 1607.5 | 248875 | 45460 | 294335 | 91690.31 | 202644.69 | 3.21 |
| $T_4$ = MLE @ 40 % | 1667.87 | 258265 | 50069.125 | 308334.15 | 91690.31 | 216643.815 | 3.36 |
| $T_5$ = MLE @ 60 % | 1744.12 | 270060 | 52656.125 | 322716.15 | 91690.31 | 231025.815 | 3.52 |
| $T_6$ = MLE @ 80 % | 1852.87 | 286900 | 59433.375 | 346333.4 | 91690.31 | 254643.065 | 3.775 |
| $T_7$ = MLE @ 100 % | 1942.87 | 300915 | 61983.375 | 362898.4 | 91690.31 | 271208.065 | 3.955 |

Detail of Table: Mungbean Grain: Rs. 157,500 /t; Mungbean Straw: Rs. 12,000 /t

Note: The price of mungbean straw in Sindh and Pakistan can vary based on factors such as location, demand, and season. As of my last knowledge update, prices might typically range from Rs. 5,000 to Rs. 10,000 per ton, but I recommend checking local markets or agricultural sources for the most current pricing. Would you like to know more about its uses or other related information?

Table 10(b): Cost of production ($ha^{-1}$) of mungbean as affected by different concentration foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean (*Vigna radiata* L.), two consecutive years of study (2023 and 2024), table used for field experiment.

| S. No. | Operation/Inputs | Quantity | Rate (Rs. Unit) | Total Expenditures |
|---|---|---|---|---|
| 1. | | Preparatory tillage | | |
| (i) | Ploughing | 3 hours | 1000 | 3000.00 |
| (ii) | Harrowing | 2 hours | 1000 | 2000.00 |
| 2. | | Seed and fertilizer | | |
| (i) | Mungbean Seed (Variety AEM-96) | 20 Kg | 475.00/kg | 9500.00 |
| (ii) | Urea FFC granular | 3 bags | 4750.00 | 14250.00 |
| (iii) | DAP (FFBL) | 2 bags | 10565.00 | 21130.00 |
| (iv) | SOP (Zarkhez Khas SOP) | 2 bags | 11300.00 | 22600.00 |
| (v) | Transportation charges | 9 bags | 350.00 | 3150.00 |
| (vi) | Application charges | 1-man $day^{-1}$ | 1000.00 | 1000.00 |
| 3. | | Irrigation | | |
| (i) | Cleaning water courses | 2-man $day^{-1}$ | 850.00 | 1700.00 |
| (ii) | Labor charges for (3-irrgations) | 1-man $day^{-1}$ | 900.00 | 2700.00 |
| (iii) | Water rates canal irrigations for mungbean | - | 160.64 $Acre^{-1}$ | 160.64 |
| 4. | Harvesting and threshing | - | 6500.00 | 6000.00 |
| 5. | Management charges | 1-man $day^{-1}$ | 1000 | 1000.00 |
| 6. | Land (Rent) | - | 25000.00 | 18000.00 |
| 7. | Weed management expenses throughout season for 2-months | 1-man $day^{-1}$ | 900.00 | 1800.00 |
| 8. | MLE foliar applications and insecticides application throughout season for 2-months | 1-man $day^{-1}$ | 850.00 | 1700.00 |
| 9. | | | | Total Expenditures = 112,190.64 |

In this investigation, various concentrations of Moringa Leaf Extract (MLE) improved photosynthetic activity, leading to significant improvements in mungbean growth and yield. The most notable increase in these attributes was observed with the foliar application of MLE @ 100 % treatment $T_7$. The enhancement in photosynthetic activity is likely due to the high concentrations of essential elements such as iron (Fe) and magnesium (Mg) found in Moringa Leaf Extract (MLE), which are crucial for chlorophyll synthesis (Ashraf et al., 2012). These findings of (Hermans et al., 2013) suggest that the application of Fe and Mg-rich Moringa Leaf Extract (MLE) could potentially improve photosynthetic activity and increase crop productivity. The results also showed a significant impact of Moringa Leaf Extract (MLE) foliar feeding on yield-related traits in mungbean, including pod length (cm), pod diameter, plant height PH (cm), branches plant$^{-1}$ BPP, pods plant$^{-1}$ PPP, seeds pod$^{-1}$ SPP, seed index-SI-1000-seed wt; (g), biological yield BY (kg ha$^{-1}$), seed yield SY (kg ha$^{-1}$), and harvest index (HI%). The most significant increases in these yield parameters occurred with MLE @ 100 % application treatment $T_7$. The higher growth promotion at this concentration is likely due to the increased quantity of growth-promoting substances in the Moringa Leaf Extract (MLE) (Vafadar et al., 2014). The improvements in yield can be attributed to the fulfillment of the plant's nutritional demands during the critical reproductive phase, which may have been effectively met by the macro and micronutrients present in Moringa Leaf Extract (MLE) (Iqbal et al., 2020). The response to Moringa Leaf Extract (MLE) varied with the concentration applied, as noted in previous studies (Rashid et al., 2021). These results align with the fact that moringa leaves and Moringa Leaf Extract (MLE) are rich in growth-promoting agents, amino acids, calcium, potassium, iron, and ascorbate. Findings of this study are consistent with previous research that emphasizes the substantial influence of Moringa Leaf Extract (MLE) on yield parameters.

Additionally, Moringa Leaf Extract (MLE) foliar application significantly improved seed nutritional content, particularly protein levels in protein content PC % from grains (Irshad et al., 2022). This improvement is due to the presence of various amino acids, soluble sugars, fiber, proline, phenols, carotenoids, ascorbic acid, and minerals such as calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), sodium (Na), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) in moringa leaves (Venkidasamy et al., 2019). Previous studies (Jain et al., 2020) have reported similar increases in growth and nutrient accumulation in plants treated with Moringa Leaf Extract (MLE). Moringa Leaf Extract (MLE) and Moringa leaves are particularly noted for their high nutritional content, containing significantly more potassium than bananas and more calcium than milk (Islam et al., 2021). In line with these findings, our study observed increased levels of potassium (K) and calcium (Ca) in mungbean seeds treated with MLE @ 100 % foliar application on different treatment $T_7$. These results are consistent with the known chemical composition of Moringa Leaf Extract (MLE), which includes high levels of ash and fiber (Biel et al., 2017). This study highlights the effectiveness of Moringa Leaf Extract (MLE), which, due to its blend of essential nutrients, antioxidants, and plant growth regulators like cytokinins, serves as a natural enhancer that promotes vegetative and reproductive growth, as well as improves agronomic and physiological traits seed nutritional content and quality in mungbean. In conclusion, foliar application of Moringa Leaf Extract (MLE) @ 100 % treatment $T_7$, significantly improved mungbean seedling growth, seed nutritional content, quality, and yield parameters (agronomic and physiological). The discussion emphasizes that MLE @ 100 % is consistently the most effective treatment across all traits for mungbean cultivation. The study strongly supports the use of MLE as a natural, eco-friendly bio-stimulant and a viable alternative or supplement to chemical fertilizers. The findings of this study underscore the potential of using Moringa Leaf Extract (MLE) @ 100 % during the reproductive stage as an effective method for promoting growth and optimizing the nutritional status of mungbean seeds. While this is a preliminary study, the results strongly support the effectiveness of this approach, highlighting its promising role as a growth enhancer for mungbean crops.

In addition to supporting our findings across both mungbean cultivation seasons (2023-2024), statistical analyses, such as regression analysis and Pearson's correlation analysis, were performed individually for field experiment across both studied years. The data (Table. 8 & Fig. 2a to 2b), presents the results of an Ordinary Least Squares (OLS) regression model results analysis, the key findings from the regression analysis field experimental season across two consecutive years of study 2023 and 2024, demonstrated a strong and significant relationship between the foliar application of Moringa Leaf Extract (MLE) and the seed yield (kg ha$^{-1}$) of mungbean (*Vigna radiata* L.). The results revealed that foliar application of Moringa Leaf Extract (MLE) significantly enhanced mungbean seed yield (kg ha$^{-1}$), with the Ordinary Least Squares (OLS) regression model explaining 85.7% of yield variation ($R^2$ = 0.857, Adjusted

$R^2$ = 0.807, p < 0.0001). The model confirmed MLE concentration as a strong predictor of yield, showing a consistent positive linear relationship. Among the treatments, MLE @ 100 % ($T_7$) exhibited the highest yield increment (543.71 kg ha$^{-1}$; p < 0.0001), followed by MLE @ 80 % (453.71 kg ha$^{-1}$), both showing highly significant effects compared to the control. These results corroborate findings by Yasmeen et al. (2023) and Hassan et al. (2023), who reported that foliar-applied MLE enhances photosynthetic efficiency, chlorophyll accumulation, and assimilate partitioning, leading to substantial yield gains in legumes. The effectiveness of higher MLE concentrations can be attributed to the abundance of natural phytohormones (zeatin, IAA, $GA_3$) and micronutrients (Zn, Fe, Mn) that synergistically promote growth and reproductive development. The moderate improvement under recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha$^{-1}$) treatment $T_2$; (137.68 kg ha$^{-1}$; $p < 0.05$) emphasizing that conventional NPK fertilization alone contributes less effectively to yield optimization compared to the bio-stimulant effects of MLE. Similar outcomes were observed by Rady et al. (2023), who demonstrated that MLE-treated crops outperform those under inorganic fertilization in terms of biomass accumulation and pod formation. This indicates that integrating MLE with balanced fertilization can enhance nutrient uptake efficiency and sustain crop productivity under semi-arid conditions. Overall, the regression outcomes affirm that the foliar application of MLE exerts a strong, concentration-dependent positive influence on mungbean yield performance. These findings reinforce the concept of MLE as a potent bio-stimulant capable of substituting or supplementing synthetic fertilizers. The results are consistent with recent literature highlighting the potential of moringa-based bio-stimulants for improving crop resilience, nutrient assimilation, and productivity under diverse agro-ecological environments (Abdalla et al., 2023; Yasmeen et al., 2023; Rady et al., 2023).

Similarly, the correlation analysis findings from the field experimental season across both years of study 2023 and 2024, emphasizing the statistical analysis of data Pearson's correlation analysis based on a two-tailed test was performed to elucidate the association in studied attributes under applied treatments as effected by foliar application of moringa leaf extract (MLE) on growth, development and yield of mungbean (*Vigna radiata* L.). The correlation matrix data (Table. 9) showed highly significant positive relationships among key agronomic and physiological traits. The results revealed a highly significant strong positive relationship between plant height PH (cm), branches plant$^{-1}$ BPP, pods plant$^{-1}$ PPP and seeds pod$^{-1}$ SPP, seed weight pod$^{-1}$ SWPP (g), and seed yield SY (kg ha$^{-1}$). Growth traits such as plant height PH (cm) and leaf area index (LAI) contribute to biomass production and support higher yield and better seed quality. This analysis underscores the impact of MLE treatments on interconnected growth and yield parameters, reinforcing that multiple foliar sprays can improve mungbean productivity. The Pearson's correlation coefficients indicated that traits such as plant height PH (cm), branches plant$^{-1}$ BPP, pods plant$^{-1}$ PPP, seeds pod$^{-1}$ SPP, seed weight pod$^{-1}$ SWPP (g), and seed yield SY (kg ha$^{-1}$) were strongly interrelated. These findings highlight the synergistic role of MLE foliar sprays in enhancing mungbean productivity by simultaneously improving growth, biomass, and yield components. Notably, the strong positive correlation (r > 0.90) observed between plant height PH (cm), and yield-related traits signifies that enhanced vegetative growth directly contributes to higher assimilate production and translocation, ultimately improving reproductive performance. Similarly, the association between pods plant$^{-1}$ PPP and seed yield SY (kg ha$^{-1}$) suggests that pod formation and seed filling are crucial determinants of productivity, which are positively influenced by the phytohormones (zeatin, IAA, and GA) and antioxidants present in MLE (Hassan et al., 2023). A close interdependence between leaf area index (LAI) and seed yield SY (kg ha$^{-1}$) was also evident, implying that greater photosynthetic area enhances assimilate partitioning towards sink organs. This finding aligns with Abdalla et al. (2023), who reported that MLE application enhances photosynthetic efficiency and nutrient uptake in legumes through improved leaf chlorophyll content and physiological activity. Furthermore, the highly significant correlations among growth and yield attributes indicate a high degree of interconnectedness among mungbean traits under MLE foliar application. The correlation matrix suggested potential multicollinearity (r > 0.98) among certain traits, particularly between yield components and plant growth variables. This statistical association reflects the comprehensive physiological enhancement induced by MLE, which improves multiple traits simultaneously (Al-Farga et al., 2024). These findings are consistent with those of Rahman et al. (2024), who noted that bio-stimulant applications such as MLE improve mungbean performance through improved hormonal balance and metabolic activation. Similarly, Kumar and Yadav (2023) found that MLE application enhanced plant height, pod number, and seed yield in pulses due to improved nitrogen metabolism

and antioxidant enzyme activity.

The data (Table. 10a) highlight the benefit-cost-ratio (BCR) analysis and cost of production ($ha^{-1}$) across two-year study (2023–2024) found that foliar application of Moringa Leaf Extract (MLE) significantly improved mungbean yield and economic returns, with benefits increasing as MLE concentration rose from 20 % to 100 %. The highest concentration MLE @ 100 % treatment $T_7$, delivered the best results: maximum yield of (1,942.87 kg $ha^{-1}$), the highest gross income of (Rs. 362,898.4 $ha^{-1}$), and a net income of (Rs. 271,208.06 $ha^{-1}$). It also recorded the highest benefit-cost-ratio of (BCR = 3.955), indicating exceptional economic viability. These findings indicate that MLE, especially at higher concentrations, is a cost-effective and sustainable strategy to enhance mungbean productivity and profitability. Similar trends were reported by Abdalla et al. (2023), who found that foliar-applied MLE improved growth, yield, and profitability in legumes under field conditions. However, besides the cost of production per hectare ($ha^{-1}$) (Rs. 112,190.64) for mungbean (*Vigna radiata* L.) cultivation under field experiment conducted in 2023 and 2024, where moringa leaf extract (MLE) was applied as a foliar bio-stimulant at varying concentrations. The data (Table. 10.b) demonstrated that the cost of production ($ha^{-1}$) the total expenditure incurred in this field experiment was (Rs. 112,190.64 $ha^{-1}$). The major cost components included preparatory tillage, seed and fertilizers inputs (urea, DAP, SOP), irrigation, harvesting, land rent, and crop management operations (including MLE and pesticide applications). Preparatory tillage involved ploughing and harrowing, totaling (Rs. 5,000.00). This approach aligns with recent global efforts to integrate natural plant bio-stimulants such as MLE into sustainable crop production systems to enhance yield while managing input costs. According to Khan et al. (2023), moringa leaf extract significantly improves nutrient uptake and stress tolerance in legumes, potentially improving cost-efficiency by reducing reliance on synthetic inputs. Similarly, Ali et al. (2024) demonstrated in field trials in Pakistan that MLE foliar sprays (at 3–5% concentration) increased mungbean yield by 18–22% without raising fertilizer costs, thereby improving the benefit-cost ratio (BCR). Conversely, for seed and fertilizer inputs, a significant portion of the cost went towards high-quality inputs such as mungbean seed (Rs. 9,500.00), Urea (Rs. 14,250.00), DAP (Rs. 21,130.00), and SOP (Rs. 22,600.00), along with associated transportation and application charges. Irrigation-related costs included watercourse cleaning, labor for three irrigations, and canal water rates, collectively amounting to (Rs. 4,560.64). Additionally, harvesting and threshing were estimated at (Rs. 6,000.00), while management and labor charges for ongoing tasks like weed control, moringa leaf extract (MLE) foliar spraying, and insecticide application added a further (Rs. 3,500.00) and land rent was listed as (Rs. 18000.00). Similar findings were reported by Kumar et al. (2023), who observed that fertilizer and seed inputs accounted for over 60% of total mungbean production costs under integrated nutrient management systems. The inclusion of MLE, as noted by Naeem et al. (2024), can enhance plant growth and yield efficiency while slightly reducing dependency on chemical fertilizers, thus optimizing overall cost-effectiveness. Additionally, Ali and Hassan (2023) highlighted that foliar bio-stimulants like MLE improve the benefit-cost-ratio (BCR) by increasing yield returns relative to total expenditure.

## CONCLUSIONS

The field experiment was conducted "Kharif" seasons during the 2023–2024, evaluated the effects of moringa oleifera leaf extract (MLE) on mungbean (*Vigna radiata* L.) growth, yield, physiological efficiency, profitability and economics across two consecutive years under varying application methods and timings proving its effectiveness as a natural bio-stimulant: The key findings from both years of study are as follows:

1. The results revealed that the exogenous application of moringa leaf extract significantly enhanced mungbean growth and yield, particularly at 100% concentration treatment ($T_7$) was most effective recorded the highest improvements in germination, plant growth, physiological parameters crop growth rate CGR ($gm^{-2}$ $day^{-1}$), net assimilation rate NAR (g $m^{-2}$ $day^{-1}$), total dry matter TDM (kg $ha^{-1}$), protein content (PC %) from grains, and seed yield SY (kg $ha^{-1}$).
2. Yield response was dose-dependent and the effectiveness of the treatments decreased in the following order: MLE @ 100% > MLE @ 80% > MLE @ 60% > MLE @ 40% > MLE @ 20 % > RDF (NPK @ 25: 50: 25 kg $ha^{-1}$) > control. Plants grown under normal conditions showed minimal growth.
3. The regression analysis, confirmed that strong treatment impact on seed yield (kg $ha^{-1}$). The Ordinary Least Squares (OLS) regression models showed a strong model fit ($R^2$ = 0.857) with highly significant treatment effects ($p < 0.0001$) indicating that approximately 85.7% of the variation in seed yield SY (kg $ha^{-1}$) could be attributed to the treatments applied. Across both years, MLE @ 100% consistently resulted in the highest seed yield SY (kg $ha^{-1}$), followed by

MLE @ 80%, MLE @ 60%, and MLE @ 40%, showing a dose-dependent improvement in yield.

4. Strong correlations (r = 0.90–0.99 ***) among growth, physiological, and yield traits such as plant height PH (cm), branches plant$^{-1}$ (BPP), seeds pod$^{-1}$ (SPP), seed weight pod$^{-1}$ SWPP (g), seed yield SY (kg ha$^{-1}$), biological yield BY (kg ha$^{-1}$), leaf area index $LAI_1$ m$^{-2}$ 21 DAS, leaf area index $LAI_2$ m$^{-2}$ 52 DAS, and leaf stem ratio g m$^{-2}$ day$^{-1}$ LSR 21 DAS, indicating that these traits mutually contributed to enhanced biomass accumulation and yield.

Overall, the results demonstrate that foliar-applied MLE significantly improved growth and productivity by strengthening interrelationships among morphological and physiological traits in mungbean (*Vigna radiata* L.).

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