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INTEGRATED USE OF NPK FERTILIZERS AND MORINGA LEAF EXTRACT (MLE) FOR THE GROWTH 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 integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean (*Vigna radiata* L. cv. AEM-96)" was carried out during two consecutive 'Kharif' seasons in four replicated randomized complete block design (RCBD) with a single factor arrangement and six treatments. It aims to compare integrated NPK + MLE treatments and determine the optimal number of foliar MLE applications for maximizing mungbean productivity. The Experiment comprised six treatments including: T_1 = Control (without MLE and NPK fertilizer), T_2 = Recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}), T_3 = NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, T_4 = NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS, T_5 = NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS and T_6 = NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS, alongside a control (without MLE) and recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) was applied in all plots to evaluate their effects on crop performance. 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 evaluated that combined effect of NPK fertilizers and moringa leaf extract (MLE) significantly enhanced mungbean performance ($P \leq 0.05$) across both years. The statistical analysis (ANOVA) revealed that combining NPK + 4 (four) foliar spray of (MLE) treatment T_6, gave the highest seed yield SY 1935 (kg ha^{-1}), plant height PH (83.33 cm), days to first seed germination DFSG (5.25 days). In contrast, the results of regression and correlation analyses, the results revealed that regression analysis showed a strong model fit ($R^2 = 0.8413$; $F = 19.099$; $p < 0.0001$). Moreover, Pearson's correlation analysis ($r > 0.99$) showed extremely strong positive relationships between seed yield SY (kg ha^{-1}) and key traits: (PH cm), (HI %), (LAI_1 m^{-2} 21 DAS), (LAI_2 m^{-2} 52 DAS), (PC %) with the highest economic return benefit-cost-ratio (BCR = 3.94). Overall, MLE, especially at 100% concentration and 200 L ha^{-1}, proved an eco-friendly bio-stimulant that boosts yield and reduces reliance on synthetic fertilizers when applied at key growth stages. Overall, the study recommends foliar application of MLE (NPK + 4 (four) foliar spray of (MLE)) @ (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: Mungbean, NPK, Days to first seed germination, Moringa leaf extract (MLE), Growth enhancers, Zeatin.

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INTRODUCTION

Mungbean (*Vigna radiata* L.), also known as green gram; belongs to kingdom plantae of family leguminoseae. 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 “impact of integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean (*Vigna radiata* L. cv. AEM-96)”. The field Experiment was laid out in four replicated randomized complete block design (RCBD) with a single factor arrangement and six 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 1st 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 and NPK fertilizer), T_2 = Recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}), T_3 = NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, T_4 = NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS, T_5 = NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS and T_6 = NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS, alongside a control (without MLE) and recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) was applied in all plots to evaluate their effects on crop performance. 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 “impact of integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield 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%, foliar applications of MLE at different timing intervals was started at (10 DAS, 20 DAS, 30 DAS, 40 DAS and 50 DAS) depending on the treatment. The number of sprays increased from one (10 DAS) to four (10–40 DAS), all applied in combination with the recommended NPK fertilizer dose such as: T_1 = Control (without MLE and NPK fertilizer), T_2 = Recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}), T_3 = NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, T_4 = NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS, T_5 = NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS and T_6 = NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS. 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 (without MLE and NPK fertilizer): no MLE applied; only 200 L ha^{-1} tap water.

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

T_3 = NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS

T_4 = NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS

T_5 = NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS

T_6 = NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS

Thus, the data Table. provides clear, calculation-ready guidelines for preparing MLE treatments, establishing a gradient from (NPK + 1, 10 DAS 20%) to (NPK + 4, 50 DAS 100%) to identify the ideal timing and 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)

NPK + 1 foliar spray of (MLE), application 10 DAS @ 20% → 20 L MLE + 80 L water

NPK + 2 foliar sprays of (MLE), application 20 DAS @ 40% → 40 L MLE + 60 L water

NPK + 3 foliar sprays of (MLE), application 30 DAS @ 60% → 60 L MLE + 40 L water

NPK + 4 foliar sprays of (MLE), application 40 DAS @ 80% → 80 L MLE + 20 L water

NPK + 5 foliar sprays of (MLE), application 50 DAS @ 100% → 100 L MLE + 0 L water

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

NPK + 1 foliar spray of (MLE), application 10 DAS @ 20% → 0.20 × 15 = 3.0 L MLE + 12.0 L water

NPK + 2 foliar sprays of (MLE), application 20 DAS @ 40% → 0.40 × 15 = 6.0 L MLE + 9.0 L water

NPK + 3 foliar sprays of (MLE), application 30 DAS @ 60% → 0.60 × 15 = 9.0 L MLE + 6.0 L water

NPK + 4 foliar sprays of (MLE), application 40 DAS @ 80% → 0.80 × 15 = 12.0 L MLE + 3.0 L water

NPK + 5 foliar sprays of (MLE), application 50 DAS @ 100% → 15.0 L MLE (no water)

Table 1: Per-hectare (ha^{-1}) spray doses and treatment details of integrated NPK fertilizers and moringa leaf extract (MLE) applied at different foliar concentrations for the growth and yield of mungbean (*Vigna radiata* L.) during 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 (L ha^{-1})	Water (L ha^{-1})
T_1 = Control (without MLE and NPK fertilizer)	0 %	No MLE applied	0	200
T_2 = Recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1})	—	NPK @ 25: 50: 25 (kg ha^{-1})	—	—
T_3 = NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS	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 = NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS	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 = NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS	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 = NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS	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 = NPK + 5 (five) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS, 40 DAS and 50 DAS	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. **Note:** The treatment T_1 (control, no MLE) and 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. The results demonstrated that 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.

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 consecutive 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 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-Pakistan.

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).

(Year-I-2023)			(Year-II-2024)	
Parameters	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 physico-chemical 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.

Table 4: Physico-chemical properties of the soil of Field Experiment, 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	22.6	22.6
Silt (%)	52.4	52.4	52.4	52.4
Clay (%)	32.8	32.8	32.8	32.8
Texture class	Silty loam	Silty loam	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.

Detail of Table:

Scientific Justification (for thesis/paper):

Soil texture cannot be recalculated numerically after harvesting because sand, silt, and clay percentages are inherent soil properties and do not change over a single crop season. Therefore, the after-harvesting soil texture remains the same as before sowing, unless soil was physically removed or added.

Note: Soil texture (sand, silt, and clay fractions) is a stable physical property and remains unchanged after harvesting; therefore, the soil retained its silty loam texture in both years of study.

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

Months	(Year-I-2023)						(Year-II-2024)					
	Week	Temperature °C			Relative Humidity (%)	Rainfall (mm)	Temperature °C			Relative Humidity (%)	Rainfall (mm)	
		Min.	Max.	Mean Temp.			Min	Max:	Mean Temp.			
March	i	14.55	37.11	33.11	90.44	0.00	6.51	32.00	22.50	86.13	4.44	
	ii	15.33	37.54	33.75	85.22	0.00	10.12	33.53	26.75	85.16	0.00	
	iii	16.25	35.00	33.58	90.11	2.21	11.55	37.55	30.25	72.00	0.00	
	iv	16.22	36.55	34.25	91.33	1.13	17.57	40.66	37.50	81.23	0.00	
Aprail	i	17.11	36.58	35.25	83.66	0.00	19.33	38.51	38.25	87.18	0.00	
	ii	19.23	40.12	39.28	87.19	0.00	18.57	41.22	39.22	83.22	Trace	
	iii	19.12	40.33	39.15	92.33	0.00	19.51	36.52	37.75	87.12	3.12	
	iv	18.23	39.51	37.75	91.22	13.15	21.58	39.59	41.25	73.10	0.00	
May	i	19.00	39.22	38.53	68.23	0.00	19.22	43.11	40.50	88.17	0.00	
	ii	22.51	45.00	45.10	84.44	0.00	23.11	44.33	45.23	86.25	0.00	
	iii	24.53	43.51	46.25	88.45	0.00	25.10	45.18	47.50	84.13	0.00	
	iv	23.19	42.00	44.11	85.11	5.19	26.13	47.52	49.75	81.44	0.00	

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

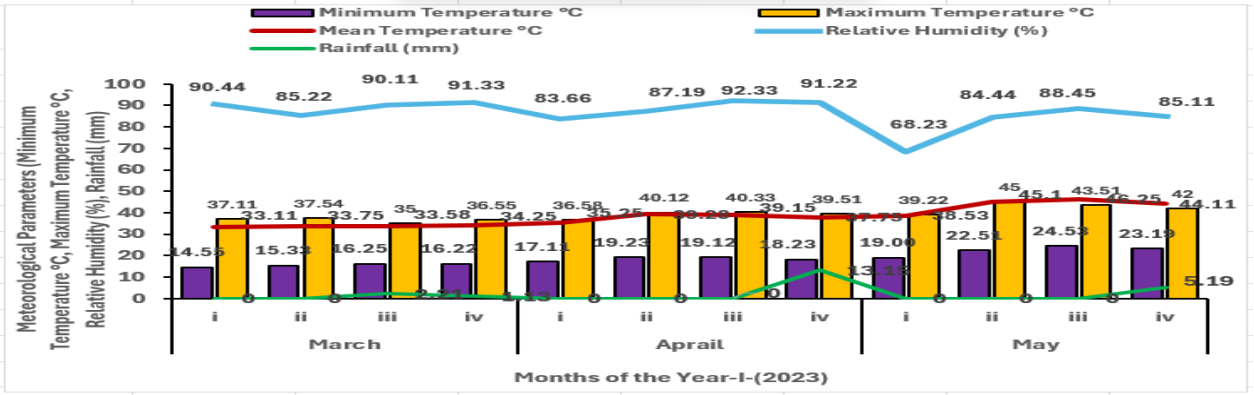


Figure 1(a): Meteorological data of Tandojam (Year-I-2023).

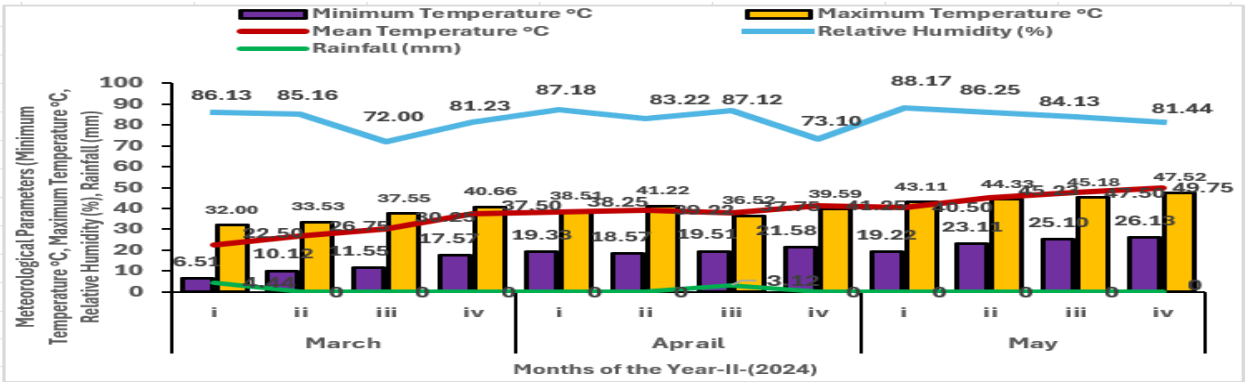


Figure 1(b): Meteorological data of Tandojam (Year-II-2024).

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.

Integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth 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) analysis of variance (ANOVA) results showed that highly significant effect of treatments on days to first seed germination (DFSG) with a (P-value of = 0.0000; $P \leq 0.05$; HSD $_{0.05}$ % = 0.5244), confirming meaningful differences among treatments. Germination was slowest in Control (without MLE and NPK fertilizer) treatment T_1 (11.12 days) and fastest in NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6 (5.25 days), showing a clear reduction in days to first seed germination (DFSG) with increasing MLE sprays combined with NPK. Overall, all MLE treatments promoted quicker germination, confirming MLE as an effective natural bio-stimulant for early crop establishment.

Plant height (PH cm)

It is evident from statistical analysis of variance (ANOVA) the data (Table. 6) revealed that a highly significant treatment effect with a (P-value of = 0.0000; $P \leq 0.05$; HSD $_{0.05}$ % = 6.11; S.E = 1.8799), confirming that integrated NPK and MLE applications significantly increased mungbean plant height (cm). Similarly, the tallest plant height was recorded in NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6 with (83.33 cm), followed by NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS treatment T_5 plant height of (75.13 cm) and NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS treatment T_4 accruing a plant height of (69.20 cm), while the Control (without MLE and NPK fertilizer) treatment T_1 had the lowest plant height (48.07 cm).

Branches plant^{-1} (BPP)

The data (Table. 6) investigates the integrated use of NPK fertilizers and Moringa Leaf Extract (MLE) treated with six different diverse foliar applications and different concentrations of Moringa leaf extract (MLE) and the recommended dose of fertilizer (RDF-NPK) applied to mungbean plants across various treatments, on the number of branches plant^{-1} in mungbean crop revealed a highly significant differences (P-value of = 0.0000; $P \leq 0.05$; HSD $_{0.05}$ % = 0.4793), indicating statistically meaningful differences among treatments. Nevertheless, branch number increased from (8.51 branches plant^{-1}) in Control (without MLE and NPK fertilizer) treatment T_1 to (14.30 branches plant^{-1}) in NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, with progressive improvement across treatments (T_2 = 11.26 branches plant^{-1}), (T_3 = 10.17 branches plant^{-1}), (T_4 = 12.31 branches plant^{-1}) and (T_5 = 13.26 branches plant^{-1}).

Pods plant^{-1} (PPP)

The data (Table. 6) analysis of variance (ANOVA) showed a highly significant effect on pods plant^{-1} (PPP) due to integrated NPK and MLE application (P-value of = 0.0000; $P \leq 0.05$; HSD $_{0.05}$ % = 4.8063; S.E. = 1.4793). Pods plant^{-1} (PPP) increased from (41.67) in Control (without MLE and NPK fertilizer) treatment T_1 to a maximum of (74.65) in NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, indicating that repeated MLE sprays with NPK markedly enhanced pod formation in mungbean.

Seeds pod^{-1} (SPP)

The data (Table. 6) suggested that analysis of variance (ANOVA) results demonstrated a highly significant effect (P-value of = 0.0000; HSD $_{0.05}$ % = 0.7699) of integrated NPK and MLE foliar sprays on seeds pod^{-1} (SPP) in mungbean. Seeds pod^{-1} (SPP) increased from (8.68) in Control (without MLE and NPK fertilizer) treatment T_1 to (14.18) in NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, with intermediate values of (10.87 seeds pod^{-1}) treatment T_2, (10.02 seeds pod^{-1}) treatment T_3, (12.10 seeds pod^{-1}) treatment T_4, and (13.28 seeds pod^{-1}) treatment T_5, emphasizing maximum seeds pod^{-1} (SPP) under treatment T_6.

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

The data (Table. 6) suggested that statistical analysis of variance (ANOVA) results revealed a highly significant effect of integrated NPK and MLE treatments on seed weight pod^{-1} (SWPP g) with a (P-value of = 0.0000; HSD $_{0.05}$ % = 0.0172), indicating meaningful differences among treatments. Seed

weight pod^{-1} (SWPP g) increased from (0.35 g) in Control (without MLE and NPK fertilizer) treatment T_1 to a maximum of (0.45 g) under NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, demonstrating a strong synergistic effect of MLE with NPK on seed development in mungbean.

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

The data (Table. 6) suggested that analysis of variance (ANOVA) results indicated a highly significant effect of integrated NPK and MLE treatments on seed index (SI-1000-seed wt; g) with a (P-value of = 0.0005; HSD $_{0.05}$ % = 4.2084), confirming clear differences among treatments.

The seed index (SI-1000-seed wt; g) increased from (50.11 g) in the Control (without MLE and NPK fertilizer) treatment T_1 to a maximum of (57.87 g) under NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, demonstrating the strong synergistic role of MLE with NPK in improving seed index (SI-1000-seed wt; g) and quality of mungbean.

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

The data (Table. 6) evaluated that analysis of variance (ANOVA) results showed that biological yield (BY kg ha^{-1}) was significantly affected by integrated NPK and Moringa Leaf Extract (MLE) application, with a (ANOVA) showing highly significant differences among treatments and (P-value of = 0.0000; HSD $_{0.05}$ % = 203.24; S. E = 62.556). Similarly, the highest biological yield (BY) was recorded in NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, with (6775.07 kg ha^{-1}), followed by NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS treatment T_5 an average biological yield BY of (6600.11 kg ha^{-1}), while the lowest biological yield BY occurred in the Control (without MLE and NPK fertilizer) treatment T_1 (5450.05 kg ha^{-1}), indicating a clear yield improvement with increased MLE foliar sprays.

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

The data (Table. 6) evaluated that analysis of variance (ANOVA) values revealed that integrating NPK fertilizer with multiple foliar sprays of Moringa Leaf Extract (MLE) significantly increased mungbean seed yield SY (kg ha^{-1}), with the highest yield (1935.10 kg ha^{-1}) achieved under NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, compared to the lowest seed yield SY (1440.50 kg ha^{-1}) in the Control (without MLE and NPK fertilizer) treatment T_1. Further, analysis of variance (ANOVA) confirmed highly significant treatment effects with a (P-value of = 0.0000; HSD $_{0.05}$ % = 120.41; S. E = 37.062) indicated clear differences among treatments, demonstrating a strong dose-dependent response to MLE application frequency.

Harvest index (HI %)

The data (Table. 6) evaluated that analysis of variance (ANOVA) results showed that integrating NPK fertilizer with multiple foliar sprays of Moringa Leaf Extract (MLE) significantly improved mungbean's harvest index (HI %), with harvest index (HI) increasing from (33.04 %) Control (without MLE and NPK fertilizer) treatment T_1 to a peak of (41.38 %) achieved under NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6. Similarly, statistical analysis confirmed highly significance with (P-value of = 0.0000; HSD $_{0.05}$ % = 1.2508; S. E = 0.3850) indicated clear differences among treatments, demonstrating a strong dose-dependent response to MLE application frequency. Incontrast, NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS treatment T_5 an average harvest index (HI) of (39.67 %) and NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, achieving a harvest index (HI) of (41.38 %) outperforming lower-spray treatments, indicating that more frequent MLE applications synergistically enhance resource allocation to seed production.

Protein content (PC %) from grains

The data (Table. 6) evaluated that analysis of variance (ANOVA) values revealed that combining NPK fertilizer with multiple foliar sprays of Moringa Leaf Extract (MLE) significantly increased protein content (PC %) from grains of mungbean, with the highest value (24.18 %) achieved under NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, compared to the Control (without MLE and NPK fertilizer) treatment T_1 (16.63 %). Further, analysis of variance (ANOVA) confirmed highly significant treatment effects with (P-value of = 0.0000; HSD $_{0.05}$ % = 1.4486; S. E = 0.4459) indicated meaningful differences between treatment means.

Physiological parameters

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

The data (Table. 6) evaluated that analysis of variance (ANOVA) results revealed that the integrated NPK fertilizer with Moringa Leaf Extract (MLE) foliar sprays significantly increased and had a positive effect on mungbean total dry matter (TDM kg ha^{-1}) subjected to different treatments in field trials with a (P-value of = 0.0000; HSD $_{0.05}$ % = 272.57; S. E = 83.894).

The highest total dry matter (TDM) (6462.54 kg ha^{-1}) was recorded at NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS

treatment T_6, indicating that this treatment was significantly greater than all other treatments also most effective in enhancing overall total dry matter TDM (kg ha^{-1}) production. Similarly, the total dry matter (TDM kg ha^{-1}) decreased progressively with later MLE applications (NPK + 3) to (RDF-NPK) and was lower with the NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS supplementation treatment T_3 showed a further reduction, producing (5837.50 kg ha^{-1}) of total dry matter (TDM) which is higher than the control but lower than most of the MLE treatments. Incontrast, the control group treatment T_1 (without MLE) had the lowest total dry matter (TDM) of (5412.51 kg ha^{-1}), confirming that integrated NPK fertilizers combining with MLE application is most effective for enhancing biomass production in mungbean crop.

Leaf area index (LAI)

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

The data (Table. 7a) evaluated that analysis of variance (ANOVA) results showed that the integrated NPK fertilizer with Moringa Leaf Extract (MLE) foliar sprays significantly increased and had a positive effect on leaf area index [LAI_1 m^{-2} (21 DAS)] of mungbean plants subjected to different treatments in field trials with a (P-value of = 0.0000; HSD $_{0.05}$ % = 0.0100; S. E = 0.003087). The highest leaf area index (LAI_1 21 DAS) of (0.28 m^{-2}) was observed in plants treated with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, while the lowest leaf area index (LAI_1 21 DAS) values was observed in 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 (0.19 m^{-2}), highlighting the importance of supplementary treatments in promoting leaf expansion and overall plant growth. Similarly, the recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) treatment T_2 also resulted in a reduced leaf area index (LAI_1 21 DAS) of (0.23 m^{-2}). Overall, the results demonstrated that leaf area index [LAI_1 m^{-2} (21 DAS)], treatment T_6 suggesting its potential to improve photosynthetic capacity and crop performance, demonstrating a synergistic enhancement in leaf growth and canopy development due to improved nutrient availability.

Leaf area index (LAI)

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

The data (Table. 7b) evaluated that analysis of variance (ANOVA) results revealed a highly significant effect (P = 0.0000) of combined NPK fertilizer and Moringa Leaf Extract (MLE) foliar sprays on mungbean leaf area index [LAI_2 m^{-2} (52 DAS)], with leaf area index [LAI_2 m^{-2} (52 DAS)] increasing from (0.88 m^{-2}) Control (without MLE and NPK fertilizer) treatment T_1 to (0.98 m^{-2}) was observed in plants treated with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6. Similarly, the HSD and low S. E values (P-value of = 0.0000; HSD $_{0.05}$ % = 0.0129; S. E = 0.003974) confirm consistent, statistically significant treatment differences, showing that more MLE sprays with NPK enhance canopy development and photosynthetic capacity.

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

The data (Table. 7) evaluated that analysis of variance (ANOVA) results revealed a highly significant effect (P = 0.0000) on mungbean leaf area duration (LAD $days^{-1}$), with values increasing from Control (without MLE and NPK fertilizer) treatment T_1 (15.41 $days^{-1}$) to recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) treatment T_2 (19.05 $days^{-1}$). The highest leaf area duration (LAD) of (24 .71 $days^{-1}$) was recorded in plants treated with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, emphasizing enhanced leaf area duration (LAD $days^{-1}$) via integrated NPK and MLE. Similarly, the HSD (5%) and (S. E) at (P-value of = 0.0000; HSD $_{0.05}$ % = 1.0194; S. E = 0.3138) confirm meaningful differences, with MLE foliar sprays progressively boosting leaf area duration (LAD), improving photosynthetic efficiency and yield potential.

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

The data (Table. 7) evaluated that analysis of variance (ANOVA) results showed a highly significant effect of integrated NPK and Moringa Leaf Extract (MLE) treatments on mungbean crop growth rate (CGR, gm^{-2} day^{-1}) with a (P-value of = 0.0000; HSD $_{0.05}$ % = 4.8831; S. E = 1.5030).

The highest crop growth rate (CGR) of (85.46 gm^{-2} day^{-1}) was observed in plants treated with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, indicating superior growth under combined nutrient management and its strong potential to enhance crop growth rate (CGR, gm^{-2} day^{-1}). Similarly, plants treated with NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS treatment T_5 showed a crop growth rate (CGR) of (78.29 gm^{-2} day^{-1}), followed by NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS treatment T_4 with a crop growth rate (CGR) of (71.98 gm^{-2} day^{-1}), recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) treatment T_2 with a crop growth rate (CGR) of (63.35 gm^{-2} day^{-1}) and NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS treatment T_3 with a crop growth rate (CGR) of (56.64 gm^{-2} day^{-1}).

Table 6: Agronomic & Physiological parameters means & standard error (S.E) of Field Experiment as effected by integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth 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	11.12 ± 0.20^{a}	48.07 ± 2.586^{e}	8.51 ± 0.2470^{f}	41.67 ± 0.972^{f}	8.68 ± 0.241^{f}	0.35 ± 0.0035^{e}	50.11 ± 0.559^{b}	5450 ± 143.61^{e}	1440.5 ± 27.707^{e}	33.04 ± 0.224^{f}	16.63 ± 0.228^{e}	5412.5 ± 269.47^{d}
T_2	8.50 ± 0.0433^{c}	63.72 ± 4.67^{cd}	11.26 ± 0.157^{d}	53.30 ± 1.2195^{d}	10.87 ± 0.333^{d}	0.39 ± 0.002c	54.12 ± 0.97^{ab}	6162.5 ± 151.4^{c}	1691.87 ± 36.4^{cd}	36.71 ± 0.717^{d}	20.68 ± 0.565^{c}	6025 ± 184.98^{bc}
T_3	9.51 ± 0.021^{b}	58.77 ± 4.119^{d}	10.17 ± 0.164^{e}	47.83 ± 1.202^{e}	10.02 ± 0.336^{e}	0.37 ± 0.0044^{d}	54.01 ± 0.637^{ab}	5900 ± 127.47^{d}	1616.25 ± 46.88^{d}	35.18 ± 0.497^{e}	18.97 ± 0.378^{d}	5837.5 ± 210.189^{c}
T_4	7.52 ± 0.021^{d}	69.20 ± 4.657^{bc}	12.31 ± 0.245^{c}	58.63 ± 1.828^{c}	12.10 ± 0.371^{c}	0.40 ± 0.0050^{c}	54.37 ± 0.907^{a}	6400 ± 127.47^{b}	1749.12 ± 30.9^{bc}	38.06 ± 0.465^{c}	21.78 ± 0.61^{bc}	6225 ± 167.23^{ab}
T_5	6.51 ± 0.0216^{e}	75.13 ± 4.435^{b}	13.26 ± 0.282^{b}	64.06 ± 2.124^{b}	13.28 ± 0.233^{b}	0.43 ± 0.0086^{b}	56.62 ± 1.036^{a}	6600 ± 93.541^{b}	1844.62 ± 30.4^{ab}	39.67 ± 0.404^{b}	23.11 ± 0.60^{ab}	6325 ± 167.23^{a}
T_6	5.25 ± 0.1250^{f}	83.33 ± 4.409^{a}	14.30 ± 0.1976^{a}	74.65 ± 2.819^{a}	14.18 ± 0.228^{a}	0.45 ± 0.0068^{a}	57.87 ± 0.872^{a}	6775 ± 108.25^{a}	1935 ± 31.324^{a}	41.38 ± 0.601^{a}	24.18 ± 0.56^{a}	6462.5 ± 157.49^{a}

Table 7: Physiological parameters means & standard error (S.E) of Field Experiment as effected by integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth 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	0.19 ± 0.0064^{f}	0.88 ± 0.0057^{f}	15.41 ± 0.3833^{f}	48.79 ± 1.852^{f}	124.06 ± 0.741^{f}	1.25 ± 0.036^{f}	2.35 ± 0.0084^{e}
T_2	0.23 ± 0.0073^{d}	0.92 ± 0.0032^{d}	19.05 ± 0.5894^{d}	63.35 ± 3.400^{d}	130.57 ± 1.069^{d}	1.43 ± 0.045^{d}	2.55 ± 0.0186^{c}
T_3	0.21 ± 0.0064^{e}	0.91 ± 0.0020^{e}	17.45 ± 0.5729^{e}	56.64 ± 2.731^{e}	127.65 ± 0.651^{e}	1.35 ± 0.039^{e}	2.45 ± 0.0166^{d}
T_4	0.25 ± 0.0046^{c}	0.94 ± 0.0015^{c}	20.59 ± 0.7023^{c}	71.98 ± 3.043^{c}	134.06 ± 0.977^{c}	1.51 ± 0.054^{c}	2.65 ± 0.0226^{b}
T_5	0.26 ± 0.0038^{b}	0.96 ± 0.0013^{b}	23.08 ± 0.7999^{b}	78.29 ± 2.874^{b}	137.45 ± 0.675^{b}	1.59 ± 0.046^{b}	2.74 ± 0.0433^{b}
T_6	0.28 ± 0.0030^{a}	0.98 ± 0.00156^{a}	24.71 ± 0.6477^{a}	85.46 ± 2.381^{a}	140.73 ± 1.268^{a}	1.71 ± 0.058^{a}	2.85 ± 0.0465^{a}

T_1 = Control (without MLE and NPK fertilizer); T_2 = Recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}); T_3 = NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS; T_4 = NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS; T_5 = NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS; T_6 = NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS

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 (48.79 gm^{-2} day^{-1}). Overall, the highly significant p-value (0.0000), confirms that MLE has a real, positive effect on mungbean superior growth under combined nutrient management.

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

The data (Table. 7) evaluated that analysis of variance (ANOVA) results showed a highly significant effect of integrated NPK and Moringa Leaf Extract (MLE) treatments on net assimilation rate (NAR, g m^{-2} day^{-1}) with a (P-value of = 0.0000; HSD $_{0.05}$ % = 2.6064; S. E = 0.8022), indicating clear differences among treatments. The lowest net assimilation rate (NAR, g m^{-2} day^{-1}) was recorded in the Control (without MLE and NPK fertilizer) treatment T_1 (124.06 g m^{-2} day^{-1}), which increased with recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) treatment T_2 alone (130.57 g m^{-2} day^{-1}) and further improved with NPK + MLE sprays. Similarly, the highest net assimilation rate (NAR, g m^{-2} day^{-1}) was achieved in NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6 with (140.73 g m^{-2} day^{-1}), followed by NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS treatment T_5 showed a net assimilation rate (NAR) of (137.45 g m^{-2} day^{-1}) and NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS treatment T_4 with a net assimilation rate (NAR) of (134.06 gm^{-2} day^{-1}), confirming the benefit of multiple MLE applications.

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 showed a highly significant effect with a (P-value of = 0.0000; HSD $_{0.05}$ % = 0.0642; S. E = 0.0198) of integrated NPK and MLE treatments on leaf stem ratio (LSR 21 DAS g m^{-2} day^{-1}) of mungbean plants. The lowest leaf stem ratio (LSR 21 DAS) was recorded in Control (without MLE and NPK fertilizer) treatment T_1 (1.25 g m^{-2} day^{-1}), while recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) treatment T_2 improved it to leaf stem ratio (LSR 21 DAS) of (1.43 g m^{-2} day^{-1}); progressive increases were observed with additional MLE sprays treatment (T_3–T_5: 1.35–1.59 g m^{-2} day^{-1}). Similarly, the highest leaf stem ratio (LSR 21 DAS) was achieved with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6 reaching (1.71 g m^{-2} day^{-1}), indicating superior biomass partitioning toward leaves.

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

(b). LSR (52 DAS)

The data (Table. 7b) evaluated that analysis of variance (ANOVA) values showed that leaf stem ratio (LSR 52 DAS g m^{-2} day^{-1}) of mungbean was significantly influenced by integrated NPK and Moringa Leaf Extract (MLE) treatments with a (P-value of = 0.0000; HSD $_{0.05}$ % = 0.0926; S. E = 0.0285). Similarly, the values of leaf stem ratio (LSR 52 DAS g m^{-2} day^{-1}) was increasing from (2.35 g m^{-2} day^{-1}) in Control group (without MLE) treatment T_1, to a maximum of (2.85 g m^{-2} day^{-1}) under NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6. Nevertheless, the highest leaf stem ratio (LSR 52 DAS) of (2.85 g m^{-2} day^{-1}) was observed in plants treated with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, confirms that combined NPK fertilization with repeated MLE foliar sprays most effectively enhanced vegetative growth and biomass allocation.

Statistical analysis (Correlation and Regression)

Regression analysis

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 integrated NPK fertilizer use and foliar applications of Moringa Leaf Extract (MLE) on mungbean seed yield (kg ha^{-1}) during the year 2023–2024, Experimental season both years of study. The model was carefully adjusted to minimize multicollinearity and demonstrates strong statistical reliability and agronomic relevance. The regression analysis showed that integrated NPK fertilizer use and foliar applications of Moringa Leaf Extract (MLE) on mungbean seed yield (kg ha^{-1}) had a highly significant effect on mungbean seed yield (kg ha^{-1}), with the model explaining 84.13% of yield variability (R-squared (R^2) = 0.84133; Adj. R-squared = 0.7972; $p < 0.0001$). The model demonstrates a strong fit with an R-squared value of 0.84133, indicating that it explains 84.13% of the variance in seed yield (kg ha^{-1}) is explained by the model, showing a very strong fit between the dependent variable seed yield (kg ha^{-1}) and the independent variables (treatments and recommended dose of fertilizer (RDF) NPK, while the the adjusted R-squared value of 0.7972 demonstrated that adjusted for the number of predictors, still indicating a strong model fit, slightly lower confirms that, even with fewer predictors, the model retains good explanatory power and demonstrates high statistical significance and strong explanatory power, but still confirms a very strong relationship. The model is highly statistically significant with a high F-statistic of (19.099, p <

0.0001; p-value: 0.00000125 $p < 0.0001$) confirming that treatments are highly significantly influence on seed yield (kg ha^{-1}). Model fit metrics, including Log-Likelihood (-138.35), the Akaike Information Criterion (AIC) (283.42), and the Bayesian Information Criterion (BIC) (290.6), indicate an information criteria useful for model comparison. Lower values indicate a better well-fitting model. All p-values for the coefficients (including the intercept, treatments, and recommended dose of fertilizer (RDF) NPK are ($P \leq 0.001$), confirming the statistical significance of all variables in predicting seed yield (kg ha^{-1}). The results highlight that all treatments significantly increased yield compared to the control, with effects increasing with the number of MLE foliar sprays: The bar-plot illustrates that the impact of different treatments on seed yield (kg ha^{-1}) in mungbean with the highest seed yield (494.500 kg ha^{-1}, $p < 0.00000007$) was achieved with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6 had the highest coefficient (+494.500), emphasizing that this treatment showed a highly significant increase in seed yield (kg ha^{-1}) with a (t-value of = 8.763, p-value = 0.00000007), indicating a strong synergistic effect between NPK and repeated MLE application. Additional MLE foliar sprays with NPK significantly increased mungbean seed yield (kg ha^{-1}), rising from 175.750 (kg ha^{-1}) with NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS treatment T_3 (175.750; $p < 0.0001$, $t = 3.114$) to 308.625 (kg ha^{-1}) with NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS treatment T_4 (308.625; $p = 0.000034$, $t = 5.469$), confirming that two sprays are more effective than one. Yield increases progressively with more MLE applications, indicating a cumulative and synergistic effect between NPK and MLE. Incontrast, NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS treatment T_5 significantly maximized seed yield (404.125 kg ha^{-1}; $p < 0.00000114$), slightly outperforming the two-spray treatment, indicating a cumulative yield benefit with later MLE applications. Nevertheless, the recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) treatment T_2 also increased yield (251.475 kg ha^{-1}; $t = 4.454$) but was less effective than NPK + MLE combinations. Notably, diagnostic tests, including Omnibus, Jarque-Bera, and Durbin-Watson, confirm that residuals are normally distributed and independent, while the low condition number (6.85) confirmed model reliability and absence of multicollinearity. Overall, the results confirm that the application of NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, in conjunction with NPK fertilizer is the most effective strategy for maximizing mungbean seed yield (kg ha^{-1}); demonstrating both statistical significance and practical Agronomic value.

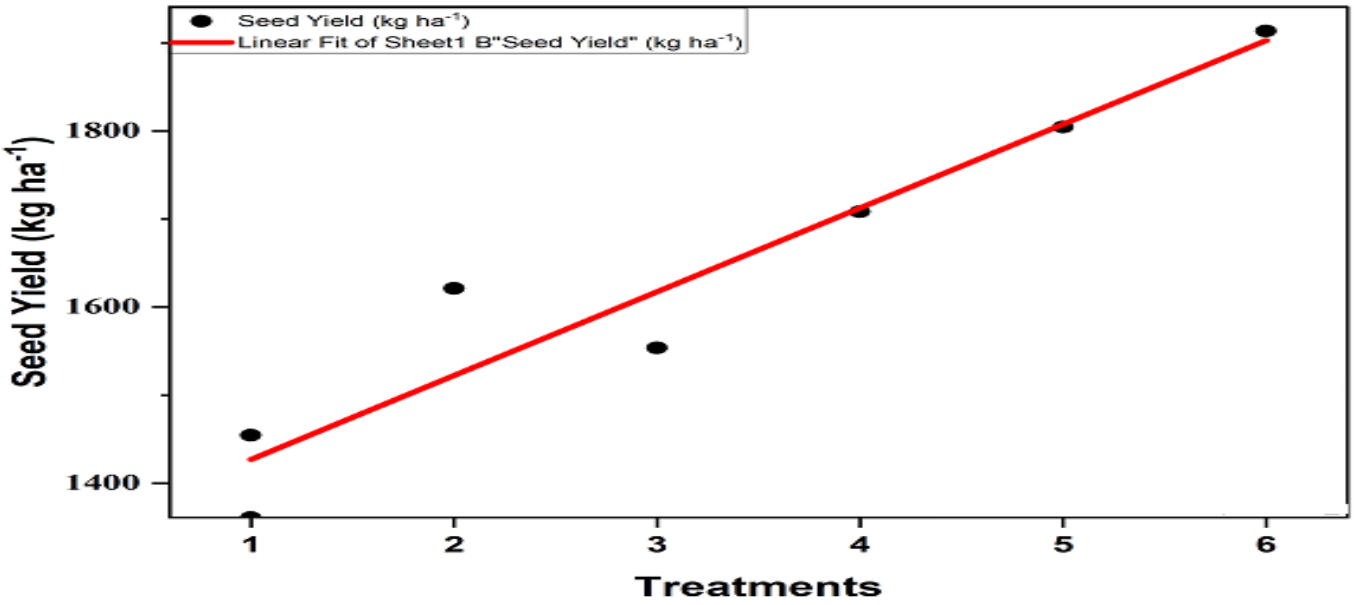


Figure 2(a): Linear regression analysis among seed yield (kg ha^{-1}) and imposed MLE applied treatments impact of integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean.

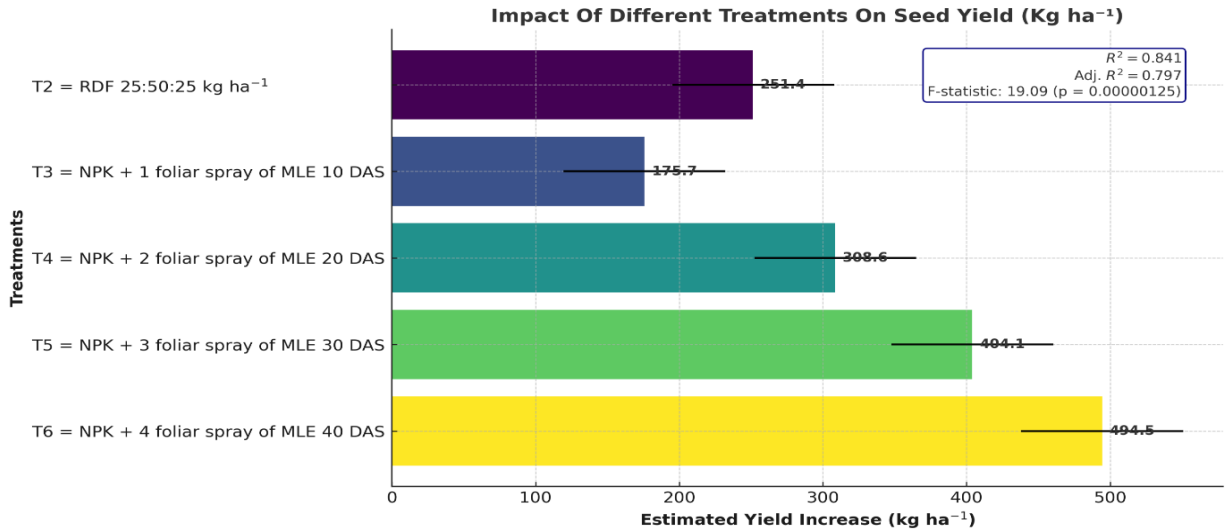


Figure 2(b): Bar-plot representation among the imposed MLE applied treatments and seed yield (kg ha^{-1}) of mungbean crop, illustrates the impact of integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean, and shows key insights into how each treatment influences yield relative to a baseline (control) during the Field Experimental season of 2023 and 2024 both years of study.

Table 8: Regression analysis values among the seed yield (kg ha⁻¹) and imposed MLE applied treatments, impact of integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean, during the Field Experimental season of 2023 and 2024 both years of study.

OLS Regression Results Model Summary Statistics:

Dep. Variable:	Seed yield (SY kg ha⁻¹)	R-squared:	0.84133
Model:	OLS	Adj. R-squared:	0.7972
Method:	Least Squares	F-statistic:	19.099
Date:	Fri, 06 June, 2025	Prob (F-statistic):	0.00000125
Time:	18:11:22 PM	Log-Likelihood:	-138.35
No. Observations:	24	AIC:	283.4266
Degrees of Freedom (DF Residuals):	18	BIC:	290.6
DF Model:	5		
Covariance Type:	non-robust		

Treatments	Coeff	Std. Err	t-value	p-value	95% CI (Lower)	95% CI (Upper)
T_2 = RDF @ 25: 50: 25 (kg ha^{-1})	251.475	56.433	4.454	0.00030632	132.814	369.936
T_3 = NPK + 1 foliar spray of MLE 10 DAS	175.750	56.433	3.114	0.00598864	57.189	294.311
T_4 = NPK + 2 foliar sprays of MLE 10 DAS and 20 DAS	308.625	56.433	5.469	0.00003404	190.064	427.186
T_5 = NPK + 3 foliar sprays of MLE 10 DAS 20 DAS and 30 DAS	404.125	56.433	7.161	0.00000114	285.564	522.686
T_6 = NPK + 4 foliar sprays of MLE 10 DAS 20 DAS, 30 DAS and 40 DAS	494.500	56.433	8.763	0.00000007	375.939	613.061

Omnibus:	0.839	Durbin-Watson:	2.556
Prob (Omnibus):	0.657	Jarque-Bera (JB):	0.741
Skew:	-0.101	Prob (JB):	0.690
Kurtosis:	2.163	Cond. No.	6.85

Correlation analysis

Pearson correlation analysis the data (Table. 9) presents the correlation matrix for various variables agronomic, physiological and yield traits, which were measured in field experiment, and conducted in two consecutive years of study 2023 and 2024. It is obvious from 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 integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean. The correlation coefficients range from (-1) to (+1), indicating the strength and direction of relationships between variables. A value closer to (+1) indicates a strong positive relationship (both variables tend to increase together) with (+1) indicating a perfect positive correlation, while a value closer to (-1) indicates a strong negative relationship (one variable tends to increase as the other decreases), (-1) indicating a perfect negative correlation, a value near zero (0) suggests little to no linear relationship or zero (0) indicating no correlation. Pearson correlation analysis results values, evaluated that our findings of current results revealed a strong positive relationship among key agronomical, physiological, and yield traits in mungbean plants (all $r > 0.99$, $p < 0.001$).

The analysis reveals those strong correlations between germination seed and various plant traits, as well as key interrelations among structural traits. The results evaluated that most of the correlations are very strong ($r > 0.90$) and positive, indicating that growth related traits increase together in response to integrated nutrient and stimulant treatments. The strongest correlations ($r \geq 0.99$) include: (plant height PH cm vs. days to first seed germination DFSG: r = 0.9988***), (leaf area index LAI_1 m^{-2} 21 DAS vs. harvest index HI %: r = 0.9989***), (crop growth rate CGR, gm^{-2} day^{-1} vs. net assimilation rate NAR, g m^{-2} day^{-1}: r = 0.9994***) and (leaf stem ratio LSR 52 DAS g m^{-2} day^{-1} vs. net assimilation rate NAR, g m^{-2} day^{-1}: r = 0.9992***) highlighting tight physiological linkages among early vigor, growth efficiency, and biomass allocation is positively related to overall plant performance. Similarly, there are strong positive correlations among key (seed yield SY kg ha^{-1}), traits that contribute to yield. Seed yield SY (kg ha^{-1}) has notable relationships with other structural traits: exhibits strong positive correlations such as (seed yield SY kg ha^{-1} and harvest index HI %: r = 0.9941***), (seed yield SY kg ha^{-1} and biological yield BY kg ha^{-1}: r = 0.9945***), (seed yield SY kg ha^{-1} and protein content PC % from grains: r = 0.9956***), (seed yield SY kg ha^{-1} and plant height PH cm: r = 0.9957***), (seed yield SY kg ha^{-1} and leaf area index LAI_2 m^{-2} 52 DAS: r = 0.9941***), (seed yield SY kg ha^{-1} and leaf stem ratio LSR 21 DAS g m^{-2} day^{-1}: r = 0.9871***) reflecting these treatments seed yield SY (kg ha^{-1}) is highly influenced by plant structure (height), physiological parameters (leaf area index LAI_2 m^{-2} 52 DAS, senescence), protein accumulation, and harvest index HI %, improving these traits tend to boost yield significantly.

Conversely, relationships among physiological parameters have exhibits strong positive correlations with (leaf area index LAI_1 m^{-2} 21 DAS and leaf area index LAI_2 m^{-2} 52 DAS: r = 0.9970***) reflecting which is expected since these two variables both measure leaf area index at different time points and are likely to follow similar patterns over time. (Leaf area index LAI_2 m^{-2} 52 DAS and leaf area duration LAD day^{-1}: r = 0.9982***) emphasizing taller plants tend to have more sustained leaf activity, further supporting growth and yield. (Crop growth rate CGR, gm^{-2} day^{-1} and net assimilation rate NAR, g m^{-2} day^{-1}: r = 0.9994***), (leaf stem ratio LSR 21 DAS g m^{-2} day^{-1} and seed weight pod^{-1} SWPP g: r = 0.9994***) demonstrating that implication of these physiological traits is interdependent. High leaf area index (LAI_1 m^{-2} 21 DAS) and leaf area index (LAI_2 m^{-2} 52 DAS) supports higher leaf area duration (LAD day^{-1}), and together they contribute to improved crop growth rate (CGR, gm^{-2} day^{-1}) and net assimilation rate (NAR, g m^{-2} day^{-1}), which relate directly to productivity. Additionally, relatively lower correlations (but still significant) show in some traits: such as (seed index-SI-1000-seed wt.; g) with most traits has moderate to strong correlations e.g., with (pods $plant^{-1}$ PPP: r = 0.9376***, with biological yield BY kg ha^{-1}: r = 0.9585***), but generally lower than others. (Seed index-SI-1000-seed wt.; g and net assimilation rate NAR, g m^{-2} day^{-1}: r = -0.9429***) reflecting implication of (seed index-SI-1000-seed wt.; g) may be influenced by other factors (e.g., genetics, water availability) more than by general vegetative growth.

Overall, this Experiment underscores the correlation matrix highlights strong positive interdependence relationships among growth traits (e.g., plant height PH cm, leaf area index LAI m^{-2}), physiological parameters (e.g., crop growth rate CGR g m^{-2} day^{-1}, net assimilation rate NAR g m^{-2} day^{-1}), and yield components (e.g., seed yield SY kg ha^{-1}, biological yield BY kg ha^{-1}, and harvest index HI %) indicating their interdependence. These findings underscore the effectiveness of combining NPK fertilizers and MLE to enhance mungbean growth and yield through integrated physiological development.

Table 9: Correlation analysis showed positive and negative interactions among studied traits under different imposed (MLE) applied treatments as effected by integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth 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	LAI21DAS	LAI52DAS	LAD	CGR	NAR	LSR21DAS	LSR52DAS
DFSG	1																		
PH	0.9988374	1																	
BPP	0.9923471	0.996496	1																
PPP	0.993725	0.992514	0.984097	1															
SPP	0.9885125	0.993915	0.995828	0.9889499	1														
SWPP	0.993986	0.996382	0.993507	0.9965344	0.997244	1													
SI	0.9629452	0.965362	0.957189	0.9376032	0.946678	0.94899688	1												
BY	0.9827556	0.988686	0.996831	0.9671181	0.987624	0.98165128	0.958532	1											
SY	0.9927036	0.995729	0.99579	0.9780918	0.987811	0.987822	0.978673	0.994494	1										
HI	0.99543	0.998417	0.998267	0.9921566	0.997558	0.99836914	0.956599	0.990736	0.994117	1									
PC	0.9857928	0.991135	0.998048	0.9732527	0.990083	0.98644333	0.958401	0.999056	0.995619	0.993948	1								
TDM	0.9720068	0.977763	0.987865	0.9476064	0.972368	0.96417546	0.956955	0.996445	0.988412	0.977595	0.992615	1							
LAI21DAS	0.9955126	0.998072	0.998705	0.9907624	0.9967	0.99632666	0.951534	0.992011	0.992911	0.998962	0.993808	0.981112	1						
LAI52DAS	0.9942567	0.997792	0.996636	0.9916874	0.997525	0.99854402	0.961651	0.988512	0.994072	0.999367	0.992186	0.974077	0.997004	1					
LAD	0.9887476	0.993199	0.991877	0.9924188	0.99791	0.99880014	0.949442	0.980629	0.98608	0.996797	0.98556	0.961696	0.993412	0.9982243	1				
CGR	0.989433	0.993691	0.995873	0.9906737	0.998994	0.99699672	0.937362	0.987032	0.985537	0.997372	0.989552	0.972134	0.997866	0.9958763	0.99594	1			
NAR	0.9909238	0.994887	0.995163	0.993181	0.999362	0.99887518	0.94294	0.985009	0.986646	0.998182	0.988472	0.968568	0.99734	0.9977163	0.998341	0.9994156	1		
LSR21DAS	0.996016	0.997094	0.992744	0.9981576	0.99567	0.99947953	0.947693	0.980107	0.987105	0.997775	0.984623	0.963434	0.996698	0.9972963	0.996812	0.9963768	0.997988	1	
LSR52DAS	0.9925107	0.995074	0.994907	0.9949444	0.997419	0.99869673	0.938111	0.984186	0.985799	0.998109	0.988242	0.967968	0.997806	0.9966322	0.996564	0.9989833	0.999224	0.9985735	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

Benefit-cost-ratio (BCR)

The data (Table. 10a) presents the benefit-cost-ratio (BCR) of mungbean two consecutive years of field study (2023–2024) was performed to elucidate the association in studied attributes under applied treatments as effected by integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean (*Vigna radiata* L.). The result demonstrated that different combinations of NPK fertilizer and MLE sprays are tested. Combining NPK fertilizer with multiple MLE sprays increases the benefit-cost-ratio (BCR). This study included six treatments: a control (without MLE and NPK), NPK fertilizer alone, and various combinations of NPK with one to four (1, 2, 3, 4) foliar sprays of MLE applied at different intervals. The economic analysis revealed a clear advantage in combining MLE with NPK fertilization. The control treatment (T_1) resulted in the lowest yield (1440.5 kg ha^{-1}) and the lowest benefit-cost-ratio (BCR) of (2.955). Application of only NPK recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) treatment (T_2) improved yield and profitability, achieving a benefit-cost-ratio (BCR) of (3.44). When MLE was combined with NPK, further improvements were observed. The addition of NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS at treatment T_3, results in a (benefit-cost-ratio) BCR of (3.29), while the application of NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS along with NPK treatment (T_4) notably enhanced net income to (Rs. 234,971.06 ha^{-1}) and benefit-cost-ratio (BCR) to (3.56). As the number of MLE sprays increased, the benefits became even more significant. The treatment involving NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS with NPK treatment (T_5) resulted in a net income of (Rs. 251,031.565 ha^{-1}) and a benefit-cost-ratio (BCR) of (3.735). Similarly, the highest yield (1935 kg ha^{-1}) and maximum benefit-cost-ratio (BCR) of (3.90) were recorded in treatment (T_6), which involved NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS along with NPK. Overall, the results indicates that the synergistic use of NPK and multiple MLE applications significantly enhances both productivity and profitability. Therefore, integrating MLE foliar sprays with NPK fertilization is recommended as a

sustainable and economically beneficial practice for mungbean cultivation.

Cost of production (ha^{-1})

The data (Table 10b) 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 integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean (*Vigna radiata* L.), 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.

Table 10(a): Benefit-cost-ratio (BCR) of mungbean as affected by integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean (*Vigna radiata* L.)., two consecutive years of study (2023 and 2024), Table used for Field Experiment.

Treatment concentrations	Yield (kg ha^{-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							
Integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean *(Vigna radiata* L.*)*.							
T_1 = Control (without MLE and NPK fertilizer)	1440.5	222880	48043.5	270923.5	91690.31	179233.19	2.955
T_2 = RDF-NPK @ 25: 50: 25 (kg ha^{-1})	1691.87	261887.5	53605.625	316973.8	91690.31	223802.815	3.44
T_3 = NPK + 1 (one) foliar spray of Moringa Leaf Extract (MLE) 10 DAS	1616.25	250206.25	51367.5	303801.3	91690.31	209883.44	3.29
T_4 = NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS	1749.12	270910	55751.375	326661.4	91690.31	234971.065	3.56
T_5 = NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS	1844.62	285717.5	57004.375	349798.3	91690.31	251031.565	3.735
T_6 = NPK + 4 (four) foliar spray of (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS	1935	299818.75	58026.25	357845.05	91690.31	266154.69	3.90

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

Cost of production is annexed in data Table-10 (b) 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 integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth 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	

DISCUSSION

The Experiment aimed to assess the effect of integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean mungbean (*Vigna radiata* L.). The field experiment was conducted during 2023–2024 evaluated the influence of foliar application of Moringa Leaf Extract (MLE) + NPK 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 integrated use of NPK fertilizers and moringa leaf extract (MLE) applications, particularly at treated with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, 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 foliar applications of Moringa Leaf Extract (MLE) + integrated use of NPK fertilizers and moringa leaf extract (MLE) applications on mungbean growth, biochemical properties, yield, and seed nutritional content. The results revealed the key findings of the study highlighted that Moringa Leaf Extract (MLE) application significantly influenced plant growth parameters, yield components, and Physiological traits. The study evaluated multiple parameters, including days to first seed germination (DFSG), plant height PH (cm), number of branches plant^{-1} BPP, pods plant^{-1} PPP, seed yield SY (kg ha^{-1}), biological yield BY (kg ha^{-1}), and physiological parameters. The alterations in morphological attributes were followed a similar trend in both years of study (2023-2024) of mungbean cultivation. This discussion centers on the effects of different combinations of NPK fertilizers and foliar applications of Moringa Leaf Extract (MLE) on multiple Agronomic, Morphological, Physiological, and yield-related traits of mungbean (*Vigna radiata* L.). The major findings across treatments are summarized below:

This study reveals the transformative effects of incorporating Moringa Leaf Extract (MLE) as a foliar bio-stimulant alongside NPK fertilizers to enhance the growth, development, and yield of mungbean (*Vigna radiata* L.). The findings emphasize the significant potential of Moringa Leaf Extract (MLE), particularly when integrated with conventional fertilization methods, in improving crop productivity through synergistic interactions. The study also recorded significant improvements in plant height PH (cm) and number of branches plant^{-1} BPP with increasing levels of NPK fertilizers and Moringa Leaf Extract (MLE) foliar sprays showing in the mean data (Table. 6). This demonstrates a synergistic effect, where NPK fertilizers supply essential macronutrients (Rietra et al., 2017), while Moringa Leaf Extract (MLE) enhances hormonal activity and strengthens the plant's resilience against environmental stresses (Nazir et al., 2023). The optimal plant height PH (cm) and branching observed in the NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, suggested that this combination supports robust vegetative growth, across both

cropping seasons, which is critical for subsequent reproductive success and these findings are align with previous results reported by (Hasanuzzaman et al., 2023; Ma et al., 2023) that moringa leaf extract (MLE) foliar supplementation had a substantial impact on gaining higher yield and physio-biochemical attributes in mungbean crop. One of the most notable observations is the substantial reduction in the time required for seed germination days to first seed germination (DFSG), with the application of Moringa Leaf Extract (MLE), particularly in combination with NPK fertilizers showing in the mean data (Table. 6). The accelerated germination in the NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, highlights the effectiveness of Moringa Leaf Extract (MLE) in promoting rapid seedling emergence (Murtaza et al., 2023). This improvement can be attributed to the bioactive compounds in Moringa Leaf Extract (MLE), such as cytokinin's, which stimulate cell division and elongation (Zulfiqar et al., 2020), alongside the enhanced nutrient availability provided by NPK fertilizers (Rawal et al., 2022). The combination of these factors creates an ideal environment for prompt and vigorous germination (Kigel, 2017). Yield components, including the number of pods plant^{-1} PPP, seeds pod^{-1} SPP, and seed weight pod^{-1} SWPP (g) showing in the mean data (Table. 6), represents remarkable enhancements with higher doses of NPK and Moringa Leaf Extract (MLE). The NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, consistently produced the highest values, indicating an optimal balance of nutrients and hormones that improves pod fertility and seed development (Dass et al., 2022). These improvements underline the importance of integrated nutrient management in achieving superior yields (Raza et al., 2023). Additionally, biological yield BY (kg ha^{-1}) showing in the mean data (Table. 6) and harvest index (HI%) showing in the mean data (Table. 6) were significantly increased by the combined application of NPK and Moringa Leaf Extract (MLE). The enhanced photosynthetic efficiency and efficient allocation of biomass to reproductive structures (Wang et al., 2008) in the NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, are evident from the observed improvements in crop growth rate CGR, (gm^{-2} day^{-1}) and net assimilation rate NAR, (g m^{-2} day^{-1}) showing in the mean data (Table. 7). Physiological traits, such as leaf area index (LAI_1 m^{-2} 21 DAS), leaf area index (LAI_2 m^{-2} 52 DAS), leaf area duration (LAD, day), and crop growth rate CGR, (gm^{-2} day^{-1}) showing in the mean data (Table. 7), responded strongly to the combined application of Moringa Leaf Extract (MLE) and NPK fertilizers. The increase in leaf area index (LAI) and leaf area duration (LAD, days^{-1}) reflects improved canopy architecture and prolonged photosynthetic activity (Li et al., 2022), both of which are crucial for sustaining plant growth and maximizing yield potential. The superior crop growth rate CGR, (gm^{-2} day^{-1}) and net assimilation rate NAR, (g m^{-2} day^{-1}) in the NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6 further illustrate the compounded benefits of nutrient availability and the bio-stimulatory effects of Moringa Leaf Extract (MLE).

A key outcome of the study is the improvement in seed protein content PC % from grains showing in the mean data (Table. 6) with increasing doses of NPK and Moringa Leaf Extract (MLE) applications. The enhanced protein content PC % from grains observed in the NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, underscores the ability of this integrated approach to promote efficient nitrogen assimilation and protein biosynthesis (Wang et al., 2024). This not only boosts seed nutritional quality but also aligns with the goals of sustainable agriculture by improving resource use efficiency (Shen et al., 2013).

In summary, the study demonstrates that the integrated use of NPK fertilizers and increasing foliar sprays of Moringa Leaf Extract (MLE) significantly enhanced mungbean performance across two growing years 2023-2024, improves mungbean growth, yield, and quality which resulted in: fastest germination, tallest plants, highest yield components, best harvest index (HI %) and enhanced protein content (PC %). The study also highlights the significant Agronomic benefits of combining Moringa Leaf Extract (MLE) with NPK fertilizers in mungbean cultivation. The highest benefits were observed in NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6 proved to be the most effective strategy, enhancing key growth, yield, and Physiological parameters while improving seed quality. These findings suggest that Moringa Leaf Extract (MLE) is rich in bioactive compounds, can be effectively used as a natural bio-stimulant to enhance mungbean production, making it a valuable approach for sustainable and environmentally friendly bio-stimulant that can effectively complement traditional fertilization practices. Future research should explore the long-term impacts of this integrated approach across diverse environmental conditions to validate its scalability and broader applicability in modern agriculture.

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) + NPK and the seed yield (kg ha^{-1}) of mungbean (*Vigna radiata* L.). The results revealed a highly significant impact of integrated NPK fertilization and foliar application of Moringa Leaf Extract (MLE) on mungbean seed yield (kg ha^{-1}). The results evaluated that the Ordinary Least Squares (OLS) regression model demonstrated a strong fit, with an R^2 and an adjusted R^2, explaining a large portion of the variability in seed yield (kg ha^{-1}) through the applied treatments. The model's high F-statistic further confirmed its statistical robustness and overall significance. Among the treatments, the combined use of NPK fertilizer with multiple early foliar applications of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, was the most effective in enhancing seed yield (kg ha^{-1}), emphasizing that this combination showed a strong and highly significant effect, highlighting its superior impact compared to other treatments. This reflects the cumulative benefit of repeated MLE application alongside balanced fertilization. Similarly, treatments combining NPK with two or three early foliar applications of NPK + 2 (two) foliar spray of Moringa Leaf Extract (MLE) 10 DAS and 20 DAS treatment T_4, NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS treatment T_5 also contributed significantly, recording mean yields of respectively. These results indicate that increasing the number of foliar applications progressively enhances crop productivity, while these treatments consistently improved seed yield (kg ha^{-1}) and maintaining strong statistical significance, confirming that the observed effects are reliable and not due to random variation. The recommended dose of fertilizer (RDF) NPK @ 25: 50: 25 (kg ha^{-1}) treatment T_2 resulted in moderate yield improvement, validating the necessity of bio-stimulant integration for enhanced productivity like Moringa Leaf Extract (MLE) for greater productivity. Diagnostic tests, including omnibus, jarque–bera, skewness, and kurtosis, confirmed the model's normality and reliability, while the condition number indicated that no multicollinearity among predictors. The model's low Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) further demonstrate its good predictive performance. These results collectively underscore that multiple MLE applications in combination with NPK fertilizer significantly boost mungbean yield by improving physiological efficiency and nutrient assimilation. Comparable findings were reported by Hassan et al. (2023) and Abdalla et al. (2023), who observed that foliar-applied MLE enhanced legume growth and yield performance under field conditions. Likewise, El-Mageed et al. (2024) highlighted MLE's bio-stimulant effect in improving nutrient uptake and seed productivity. Recently, Singh and Patel (2024) and Zafar et al. (2022) also demonstrated that integrating organic bio-stimulants with mineral fertilizers substantially improves mungbean yield and soil health. Previous investigation conducted by Aslam (2013) revealed that moringa leaf extract foliar spray is highly effective in enhancing the yield of green leafy vegetables. In summary, the regression outcomes confirm that combining NPK fertilizer with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6 represents the most effective strategy for maximizing mungbean yield. The strong statistical indicators and consistency across two seasons affirm the robustness of this integrated approach, supporting sustainable intensification of pulse production under field conditions. The evidence is statistically significant and agronomically meaningful, reinforcing the value of combining organic bio-stimulants like MLE with conventional fertilizers for sustainable crop production.

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 integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth 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 associations among major Agronomic, Physiological, and yield-related traits of mungbean under integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean treatments. The findings demonstrated that most of the growth and Physiological parameters were strongly and positively interrelated, suggesting that improvements in one parameter tend to enhance others concurrently. The correlation analysis showed a strong positive correlation between (pods $plant^{-1}$ PPP) and other traits like (plant height

PH cm), (branches plant^{-1} BPP), and (seed yield SY kg ha^{-1}) and (biological yield BY kg ha^{-1}), indicating that better vegetative growth leads to higher yields. Seed yield SY (kg ha^{-1}) also correlates highly with (seeds pod^{-1} SPP) and (biological yield BY kg ha^{-1}), showing that both reproductive success and biomass contribute to yield. This strong synergistic positive interaction clearly indicated that MLE application plays a key role in boosting the morpho-physiological and yield attributes in mungbean crop. It further highlights the key relationships between plant growth metrics, with particularly strong links observed between leaf area index (LAI_1 m^{-2} 21 DAS) and leaf area index (LAI_2 m^{-2} 52 DAS), biological yield BY (kg ha^{-1}) and productivity measures, indicating that these factors are closely interrelated in the experiment. Similarly, the relationships between crop growth rate CGR, (gm^{-2} day^{-1}), and net assimilation rate NAR (gm^{-2} day^{-1}), as well as between leaf area duration (LAD day^{-1}), and leaf area index (LAI m^{-2}) were near-perfect correlation, highlighting the synchronized functioning of photosynthetic and assimilatory processes contributing to higher productivity. Comparable results were reported by Hassan et al. (2023), who noted that MLE-induced enhancement in leaf expansion and photosynthetic efficiency significantly improved legume yield performance. Moreover, seed yield SY (kg ha^{-1}) exhibited highly significant positive correlations with plant height PH (cm), harvest index (HI %), biological yield BY (kg ha^{-1}), and protein content (PC %), indicating that structural vigor and assimilate partitioning were major determinants of final yield. These results are consistent with the findings of Abdalla et al. (2023) and El-Mageed et al. (2024), who reported that integrated MLE and balanced nutrient management improved physiological efficiency and yield attributes in mungbean and soybean. Moderate correlations observed between seed index (SI-1000-seed wt; g) and certain growth traits (e.g., pods plant^{-1} PPP, biological yield BY (kg ha^{-1}), and net assimilation rate NAR (gm^{-2} day^{-1}) suggest that seed weight may be influenced by genetic or environmental factors beyond general vegetative growth patterns. This agrees with the observations of Zheng et al. (2024), who emphasized that genotypic variation and soil moisture regimes often affect seed filling more than vegetative growth. Overall, the correlation analysis confirms a strong interdependence among growth, physiological, and yield traits under MLE-integrated nutrient management. The results highlight that enhancing early growth parameters plant height PH (cm), leaf area index (LAI m^{-2}), crop growth rate CGR, (gm^{-2} day^{-1}), net assimilation rate NAR (gm^{-2} day^{-1}) leads to better biomass accumulation, nutrient use efficiency, and ultimately higher seed yield. Similar interrelationships were recently emphasized by Kumar and Singh (2025) and Rahman et al. (2023), supporting the role of plant biostimulants and integrated fertility systems in improving mungbean productivity and resilience. In summary, the results suggest that the strong intercorrelations support the effectiveness of integrated use of NPK fertilizers and MLE in improving the growth and yield of mungbean with particularly NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6 was statistically validated as a highly promising treatment for gaining higher mungbean productivity and morpho-physiological attributes in both cropping seasons.

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 integrated use of NPK fertilizers and moringa leaf extract (MLE) for the growth and yield of mungbean (*Vigna radiata* L.) significantly improved mungbean yield and economic returns, with benefits increasing as MLE applications treated with NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6. The results revealed a noticeable trend indicating that integrating NPK fertilizer with foliar sprays of moringa leaf extract (MLE) significantly improved mungbean yield and economic returns compared to control and NPK alone. Economic analysis revealed a clear synergistic effect: profitability benefit-cost-ratio (BCR, net income) increased progressively from 1 to 4 MLE sprays applied at successive growth stages. Similarly, the control (without MLE and NPK fertilizer) treatment T_1 had the lowest yield and returns, while NPK alone improved performance; however, NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, achieved the highest productivity and economic efficiency. Overall, combining repeated MLE foliar sprays with NPK is recommended as a sustainable and cost-effective nutrient management strategy for mungbean cultivation. Comparable results were observed by Kumar et al. (2024), who reported that combining organic bio-stimulants with balanced fertilization improved profitability and sustainability in pulse-based systems. Furthermore, El-Mageed et al. (2023) highlighted that MLE enhances nutrient uptake and water-use efficiency, resulting in improved economic indices under diverse field conditions.

However, besides the cost of production per hectare (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. The data (Table. 10.b) demonstrated that that the cost of production (ha^{-1}) the total expenditure incurred in these three field experiments. This reflects the overall investment required to conduct the trials and implement the treatments. 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 consisted of essential field operations such as ploughing and harrowing. These practices are necessary to create a suitable seedbed and ensure proper crop establishment. 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, a substantial part of the production cost was invested in high-quality seeds and fertilizers, emphasizing their key role in enhancing crop growth. Additional expenses for transportation and application further contributed to the overall input costs. Irrigation-related expenses covered watercourse maintenance, labor for multiple irrigations, and canal water charges. These costs are essential for ensuring adequate water supply and supporting optimal crop growth. Additionally, the costs of harvesting and threshing represent a key component of total production expenses. These operations are crucial for efficiently collecting and processing the crop, while management and labor costs for activities such as weed control, MLE foliar spraying, and pest management contributed significantly to production expenses. Further, land rent represented a notable portion of the overall costs. 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. Overall, this cost structure reflects a comprehensive input-intensive cultivation model that balances conventional fertilizers with bio-stimulant foliar treatments of moringa leaf extract (MLE), ensuring a robust economic analysis for evaluating the cost of production (ha^{-1}) and benefit-cost-ratio (BCR) across different experimental treatments.

CONCLUSIONS

The field experiment was conducted during the "Kharif" seasons of 2023-2024 to evaluate the effects of the integrated use of NPK fertilizers and moringa leaf extract (MLE) on the growth and yield of mungbean (*Vigna radiata* L.). The study specifically assessed the crop's physiological efficiency, profitability, and economic returns in response to foliar applications of MLE across two consecutive years, using varying application methods and timings. The results consistently demonstrated MLE's effectiveness as a natural bio-stimulant. The key findings from both years of the study are as follows:

1. The results revealed that the exogenous application of Moringa Leaf Extract (MLE) combination with NPK supply particularly NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, produced the highest yield gains across both years, followed by NPK + 3 (three) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS and 30 DAS treatment T_5, demonstrating the cumulative advantage of multiple MLE applications over fertilizer use alone proved to be the most efficient in enhancing both growth and yield in mungbean plants emphasizing synergistic effects of MLE with NPK fertilizers.
2. The treatments' performance rank and effectiveness decreased in the following order: NPK + 4 > NPK + 3 > NPK + 2 > RDF (NPK) > NPK +1 > control.
3. The regression analysis, confirmed that strong treatment impact on seed yield SY (kg ha^{-1}). The regression analyses revealed that the integrated use of NPK fertilizers and Moringa Leaf Extract (MLE) had a significant impact on mungbean seed yield SY (kg ha^{-1}), with highly significant results. The regression models showed strong explanatory power with (R-squared R^2) values, confirming model robustness and treatment significance. The F-statistics for both years confirming that treatments are highly significantly influence on seed yield SY (kg ha^{-1}), this strongly supports the effectiveness of Moringa Leaf Extract (MLE) applications.
4. The correlation matrices across both years revealed strong positive and high relationships between plant growth

parameters, physiological traits, and yield components. Seed yield SY (kg ha^{-1}) was highly correlated with pods $plant^{-1}$ PPP, seeds pod^{-1} SPP, biological yield BY (kg ha^{-1}) and plant height PH (cm), while early germination favored better growth and yield. Overall, MLE foliar applications, especially the NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, significantly enhanced growth efficiency, biomass production, and yield, confirming their potential as an effective yield-boosting strategy for mungbean cultivation.

5. The economic analysis revealed that the integration of NPK fertilizer with multiple foliar sprays of Moringa Leaf Extract (MLE) significantly enhanced mungbean yield and economic returns with the most effective treatment was NPK + 4 (four) foliar spray of Moringa Leaf Extract (MLE) 10 DAS, 20 DAS, 30 DAS and 40 DAS treatment T_6, which provided the highest benefit-cost-ratio (BCR) and maximum profitability.

6. The analytical evaluation of moringa oleifera leaf extract (MLE) over two consecutive years 2023 and 2024, showed that MLE remained nutrient-rich across years, with slightly higher potassium (K) and manganese (Mn) levels and stable macro and micronutrient balance, validating its quality as a bio-stimulant. Overall, the findings confirm that moringa oleifera leaf extact (MLE) maintain a nutritionally rich composition, though environmental or physiological factors may cause year-to-year variations. These results reinforce the potential of moringa leaf extract (MLE) as a valuable bio-stimulant source for sustainable crop growth, warranting continued monitoring of its nutrient dynamics.

7. The High-Performance Liquid Chromatography (HPLC) analysis revealed that the concentration of (Zeatin) in moringa oleifera leaf extract was considerably higher in 2023 compared to 2024, despite similar environmental conditions. This sharp decline suggests potential influences from extraction techniques, plant maturity, or cultivation practices rather than temperature or humidity. Overall, the findings highlight year-to-year variability in phytochemical content, emphasizing the need for consistent extraction methods and further investigation into factors affecting Zeatin concentration in Moringa leaf extracts (MLE).

AUTHOR CONTRIBUTIONS

Muhammad Imran Zakria M.I.Z.; conceptualized the study, designed the Experiment, conducted field trials during the "Kharif" seasons of 2023 and 2024, performed data analysis, and prepared the manuscript draft. Aijaz Ahmed Soomro A.A.S.; investigation and data curation, supervised the research and experimental procedures and provided technical guidance throughout the study. Mahmooda Buriro M.B.; formal analysis, assisted in data collection and laboratory analysis: including nutrient and phytochemical assessments of moringa leaf extract (MLE) and mungbean grains. Wajid Ali Jatoi W.A.J.; contributed to experimental layout and statistical interpretation using Statistix-8.1, and validation of Agronomic results. Hamayoon Shahzad H.S.; and Hafsa Parveen H.P.; contributed to the study by providing essential financial support that facilitated the Experimental work. Hafsa Parveen H.P.; also assisted in conceptual discussions and manuscript revision. Hamayoon Shahzad H.S.; contributed to project administration and resource coordination. Asif Ali Kaleri A.A.K.; supported soil analysis, field trials, manuscript preparation and interpretation of soil physico-chemical data. All authors reviewed, revised, and approved the final version of the manuscript and supported the research dissemination.

COMPETING OF INTEREST

The authors declare that (no conflict of interest), they have no known competing financial or personal interests that could have appeared to influence the work reported in this article.

REFERENCES

Abd El-Hack, M.E., Alqhtani, A.H., Swelum, A.A., El-Saadony, M.T., Salem, H.M., Babalghith, A.O. and El-Tarabily, K.A. (2022) 'Pharmacological, nutritional and antimicrobial uses of *Moringa oleifera* Lam. leaves in poultry nutrition: an updated knowledge', *Poultry Science*, 101(9), 102031.

Abdalla, M.A., El-Monem, A.M.A., El-Ghamry, A.M. and El-Hendawy, S.E. (2023) 'Moringa leaf extract as a sustainable biostimulant for enhancing growth and yield performance in legumes', *Journal of Agronomy*, 13(2), p. 422.

Ali, F. and Hassan, S. (2023) 'Effect of bio-stimulant foliar sprays on cost–benefit ratio and yield of mungbean (*Vigna radiata* L.)', *International Journal of Plant Production*, 17(2), pp. 243–252.

Ali, M., Aslam, M.M. and Jaffar, M.A.B. (2024) 'Selection of mungbean (*Vigna radiata* L.) mutants with respect to seasonal variation of summer and spring using discriminant function analysis', *Heliyon*, 10(10), pp. 67–92.

Ali, Z., Hassan, T., Khan, H.M.R. and Nasir, N. (2023) 'A bibliometric analysis of Consumer Price Index

(CPI) from 1999–2022 using VOSviewer', *Pakistan Journal of Humanities and Social Sciences*, 11(2), pp. 2496–2505. https://doi.org/10.52131/pjhss.2023.1102.0548

AOAC (1984) *Official methods of analysis*. 14th edn. Washington, DC: Association of Official Analytical Chemists.

Arain, G.N. (2012) 'Valley mungbean cultivation in Pakistan', *International Journal of Agronomy*, 22(2), pp. 20–27.

Aslam, M. (2013) *Effect of natural growth promoters on the nutritive quality and antioxidant attributes of leafy green vegetables*. PhD thesis. University of Agriculture, Faisalabad, Pakistan.

Bashir, K.A., Bawa, J.A. and Mohammed, I. (2014) 'Efficacy of leaf extract of drumstick tree (*Moringa oleifera* Lam.) on the growth of local tomato (*Lycopersicon esculentum*)', *IOSR Journal of Pharmacy and Biological Sciences*, 9(4), pp. 74–79.

Bouyoucos, G.J. (1962) 'Hydrometer method improved for making particle size analysis of soils', *Agronomy Journal*, 54(5), pp. 179–186.

Chapman, H.D. and Pratt, P.F. (1961) *Methods of analysis for soils, plants and waters*. Berkeley: University of California.

Dass, A., Rajanna, G.A., Babu, S., Lal, S.K., Choudhary, A.K., Singh, R. and Kumar, B. (2022) 'Foliar application of macro- and micronutrients improves productivity, economic returns and resource-use efficiency of soybean in a semiarid climate', *Sustainability*, 14(10), 5825.

El-Mageed, T.A., Hassan, F.A.S. and Abdalla, M.A. (2023) 'Synergistic impact of moringa extract and mineral fertilizers on growth, yield and water-use efficiency in legumes', *Frontiers in Plant Science*, 14, 1198456.

El-Mageed, T.A., Khalifa, N.S. and El-Sherbiny, R. (2024) 'Synergistic impact of moringa leaf extract and mineral nutrition on growth and yield of legumes', *Plant Physiology Reports*, 29(1), pp. 133–145.

El-Mageed, T.A., Soliman, W.S. and Omar, A.E. (2024) 'Eco-friendly moringa-based foliar sprays improve photosynthetic traits, biomass and productivity in cowpea under arid conditions', *Scientific Reports*, 14, 15864.

Government of Pakistan (2021) *Economic survey of Pakistan*. Islamabad: Ministry of Finance.

Hanumantha Rao, B., Seleiman, M.F., Aslam, M.T., Alhammad, B.A., Hassan, M.U., Maqbool, R., Chattha, M.U. and Battaglia, M.L. (2016) 'Salinity stress in wheat: effects, mechanisms and management strategies', *Phyton*, 91(4), pp. 75–128.

Hasanuzzaman, M., Raihan, M.R.H., Nowroz, F. and Nahar, K. (2023) 'Insight into physiological and biochemical mechanisms of biostimulating effect of *Ascophyllum nodosum* and *Moringa oleifera* extracts to minimize cadmium-induced oxidative stress in rice', *Environmental Science and Pollution Research*, 30(19), pp. 55298–55313.

Hassan, F.A.S., Abdalla, M.A. and Omar, A.E. (2023) 'Physiological and biochemical responses of mungbean to foliar-applied moringa leaf extract under field conditions', *Plants*, 12(1), 87.

Hoque, T.S., Rana, M.S., Zahan, S.A., Jahan, I. and Abedin, M.A. (2020) 'Moringa leaf extract as a biostimulant on growth, yield and nutritional improvement in cabbage', *Asian Journal of Medical and Biological Research*, 6(2), pp. 196–203.

Horwitz, W., Kamps, L.R. and Boyer, K.W. (1980) 'Quality assurance in the analysis of foods and trace constituents', *Journal of the Association of Official Analytical Chemists*, 63(6), pp. 1344–1354.

Humphries, E.C. (1956) 'Mineral components and ash analysis', in Paech, K. and Tracey, M.V. (eds.) *Modern methods of plant analysis*. Vol. 1. Berlin: Springer, pp. 468–502.

Kigel, J. (2017) 'Seed germination in arid and semiarid regions', in Bradford, K.J. and Nonogaki, H. (eds.) *Seed development and germination*. Boca Raton: CRC Press, pp. 645–699.

Kumar, P., Verma, S. and Chauhan, R. (2024) 'Economic evaluation of integrated nutrient management in pulse-based cropping systems', *Journal of Plant Nutrition*, 47(6), pp. 1012–1024.

Li, Y., Ming, B., Fan, P., Liu, Y., Wang, K., Hou, P. and Xie, R. (2022) 'Quantifying contributions of leaf area and longevity to leaf area duration under increased planting density and nitrogen input regimens during maize yield improvement', *Field Crops Research*, 283, 108551.

Ma, X., Huang, D., Huang, C., Tong, Y., Yuan, F., Ma, X. and Fu, S. (2023) 'Application of nitrogen, phosphorus and potassium regulates growth and morphological development of *Torreya grandis* saplings', *Horticulture*, 9(11), 1203.

Makkar, H.P.S., Francis, G. and Becker, K. (2007) 'Bioactivity of phytochemicals in some lesser-known plants and their effects and potential applications in livestock and aquaculture production systems', *Animal Feed Science and Technology*, 137(1–2), pp. 1–9.

Malik, B.A. (2016) 'Grain legumes', in Bashir, E. and Bantel, R. (eds.) *Crop production*. Islamabad: National Book Foundation, pp. 277–328.

Murtaza, G., Ahmed, Z., Eldin, S.M., Ali, B., Bawazeer, S., Usman, M. and Tariq, A. (2023) 'Biochar–soil–plant interactions: a cross talk for sustainable agriculture under changing climate', *Frontiers in Environmental Science*, 11, 1059449.

Nair, R.M., Yang, R.Y., Easdown, W.J., Thavarajah, D., Thavarajah, P., Hughes, J.D.A. and Keatinge, J.D.H. (2013) 'Biofortification of mungbean (*Vigna radiata*) as a whole food to enhance human health', *Journal of the Science of Food and Agriculture*, 93(8), pp. 1805–1813.

Nazir, F., Kumari, S., Mahajan, M. and Khan, M.I.R. (2023) 'An explicit story of plant abiotic stress resilience: overtone of selenium, plant hormones and other signaling molecules', *Plant and Soil*, 486(1), pp. 135–163.

Nouman, W., Siddiqui, M.T., Basra, S.M.A. and Ahmed, M. (2012) '*Moringa oleifera* leaf extract: an innovative priming tool for rangeland grasses', *Turkish Journal of Agriculture and Forestry*, 36(1), pp. 65–75.

Omar, A.E., Khalid, M.H. and Abdalla, M.A. (2024) 'Eco-friendly enhancement of seed yield and biochemical quality in legumes through moringa leaf extract biostimulation', *Journal of Plant Nutrition and Physiology*, 302, 113243.

Pataczek, L., Zahir, Z.A., Ahmad, M., Rani, S., Nair, R.M., Schafleitner, R. and Hilger, T. (2018) 'Beans with benefits: the role of mungbean (*Vigna radiata*) in a changing environment', *American Journal of Plant Sciences*, 9(7), pp. 1577–1600.

Rawal, N., Pande, K.R., Shrestha, R. and Vista, S.P. (2022) 'Nutrient use efficiency (NUE) of wheat (*Triticum aestivum* L.) as affected by NPK fertilization', *PLOS ONE*, 17(1), e0262771.

Rietra, R.P., Heinen, M., Dimkpa, C.O. and Bindraban, P.S. (2017) 'Effects of nutrient antagonism and synergism on yield and fertilizer use efficiency', *Communications in Soil Science and Plant Analysis*, 48(16), pp. 1895–1920.

Ryan, A.M. (2001) 'The peer group as a context for the development of young adolescent motivation and achievement', *Child Development*, 72(4), pp. 1135–1150.

Sequeros, T., Ochieng, J., Schreinemachers, P., Binagwa, P.H., Huelgas, Z.M., Hapsari, R.T. and Suebpongsang, P. (2021) 'Mungbean in Southeast Asia and East Africa: varieties, practices and constraints', *Agriculture & Food Security*, 10(1), pp. 1–13.

Shen, J., Cui, Z., Miao, Y., Mi, G., Zhang, H., Fan, M. and Zhang, F. (2013) 'Transforming agriculture in China: from solely high yield to both high yield and high resource use efficiency', *Global Food Security*, 2(1), pp. 1–8.

Singh, R. and Patel, V.K. (2024) 'Integrated nutrient management using moringa extracts enhances productivity and sustainability in pulses', *Journal of Plant Nutrition*, 47(3), pp. 556–569.

Statistix (2006) *Statistix 8.1 user guide*. Tallahassee, FL: Analytical Software.

Tandon, H.L.S. (ed.) (2005) *Methods of analysis of soils, plants, waters, fertilisers and organic manures*. 2nd edn. New Delhi: Fertilizer Development and Consultation Organization.

Trigo, A.K., Ullah, A., Khan, F., Khan, N., Mehmood, S., Fahad, S., Datta, R. and Hussain, G.S. (2021) 'Production of organic fertilizers from rocket seed (*Eruca sativa* L.), chicken peat and *Moringa oleifera* leaves for growing linseed under water deficit stress', *Sustainability*, 13(1), 59.

Walkley, A. and Black, I.A. (1958) 'An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method', *Soil Science*, 37, pp. 29–38.

Wang, H., Yang, Y., Yao, C., Feng, Y., Wang, H., Kong, Y. and Deng, G. (2024) 'Correct combination and balance of macronutrients nitrogen, phosphorus and potassium promote plant yield and quality through enzymatic and antioxidant activities in potato', *Journal of Plant Growth Regulation*, pp. 1–19.

Wang, N., Yu, F.H., Li, P.X., He, W.M., Liu, F.H., Liu, J.M. and Dong, M. (2008) 'Clonal integration affects growth, photosynthetic efficiency and biomass allocation, but not competitive ability, of the alien invasive *Alternanthera philoxeroides* under severe stress', *Annals of Botany*, 101(5), pp. 671–678.

Williams, S. and Twine, M. (1961) 'Flame photometric method for sodium, potassium and calcium', in Paech, K. and Tracey, M.V. (eds.) *Modern methods of plant analysis*. Vol. 5. Berlin: Springer, pp. 3–5.

Yi-Shen, Z., Shuai, S. and FitzGerald, R. (2018) 'Mungbean proteins and peptides: nutritional, functional and bioactive properties', *Journal of Food & Nutrition Research*, 62(2), pp. 12–25.

Zafar, S., Khan, N. and Ahmed, A. (2022) 'Effect of biostimulants and NPK fertilization on mungbean productivity and soil health', *Pakistan Journal of Agricultural Sciences*, 59(4), pp. 945–953.

Zheng, L., Chen, Y. and Li, J. (2024) 'Influence of genotype and environment on seed filling and yield components in legumes under biostimulant treatments', *Plant Physiology Reports*, 29(1), pp. 67–78.

Zulfiqar, F., Younis, A., Finnegan, P.M. and Ferrante, A. (2020) 'Comparison of soaking corms with moringa leaf extract alone or in combination with synthetic plant growth regulators on the growth, physiology and vase life of sword lily', *Plants*, 9(11), 1590.