Journal of Agriculture and Veterinary Science
ISSN: 2959-1198 (Print), 2959-1201 (Online)

Check for updates

ROOTS PRESS

Research Article

Evaluating the Impact of *Moringa Oleifera* Leaf Extract on Drought Stress Mitigation to Enhance Growth and Yield in Mung Bean (*Vigna radiata)*

Muhammad Haris[1], Sajid Ali[2], Mehreen Hassan[3*], Adnan Zahid[3], Muhammad Taqqi Abbas[2] , Ammara Fatima[4], Bushra Zulfiqar[5], Zaira Ahmad[4], Sumaira Maqsood[6], Syed Zia ul Hasan[7]

[1]*Department of Agronomy, Faculty of Agricultural Sciences, University of the Punjab Lahore, Pakistan.*
[2]*Department of Plant Pathology, Faculty of Agricultural Sciences, University of the Punjab Lahore, Pakistan.*
[3]*Faculty of Agricultural Sciences University of the Punjab Lahore, Pakistan.*
[4]*Department of Environmental sciences, Lahore College for women University Lahore, Pakistan.*
[5]*Citrus Research Institute Sargodha, Pakistan.*
[6]*Department of Environmental Sciences Kohsar University Murree, Pakistan.*
[7]*Hill Fruit Research Station Sunny bank Murree, Pakistan.*

ABSTRACT

Vigna radiata (mung bean) is a well-known agricultural crop with high nutritional value and adaptability. In volatile climates, drought stress poses a threat to its production. Moringa Leaf Extract (MLE) is a natural remedy that includes bioactive ingredients and eco-friendly organic fertilizer. In order to improve plant growth, productivity, water usage effectiveness, and nutrient availability, MLEs are essential for controlling drought stress. This mixture strengthens agricultural resilience and works well with habitats that lack water. The purpose of this study was to determine whether an extract from moringa leaves may help preserve Mung agriculture from drought stress. Three water conditions were used to grow the seeds: normal (control; 100% field capacity), moderate (75%), and severe (50%). Then, to aid in growth and the creation of pods, moringa leaf extracts (Control: no MLE, 5x, 10x, and 20x dilutions) were sprayed as foliar spray at various points during germination, vegetative growth, reproductive development, and pod formation. Agronomic, yield, and grain quality indicators in agricultural crops were severely impacted by water stress, although leaf extracts at a 5x dilution dramatically improved root dry weight, shoot dry weight, and the number of pods and seeds harvested under both favorable and unfavorable growing circumstances. Extract has significantly increased the germination rate to 15% compared to seed that was sowed during a drought. In a similar vein, the use of MLE raised shoot and root dry weight by 62% as compared to plants under severe drought conditions. The number of pods dramatically increased by 57% compared to the plant in drought-stricken conditions. The seeds were positively impacted by MLE with a 5x dilution as it increased their quantity by 60% in comparison to the plant under drought, which had the greatest 100 seed weight of 6.02g. Regarding the drought-stressed plant, 5x diluted MLE likewise had a positive impact on biological yield and grain yield, which increased to 73 and 93%, respectively. A 77% rise in the harvest index between the MLE-applied crop and the drought-stressed crop is also notable. From this study, it can be inferred that 5x Dilution leaf extract has a stronger bio stimulant capacity than other Dilutions, which could assist Mung bean seeds produce more seeds and lessen the effects of drought stress.

Keywords: *Vigna radiata*, Drought Stress, Moringa.

OPEN ACCESS

Correspondence
Syed Zia ul Hasan
ziahfrs@gmail.com

Article History
Received: July 20, 2024
Accepted: August 25, 2024
Published: August 30, 2024

INTRODUCTION

Mung bean (*Vigna radiata*) is the third most valuable grain legume crop worldwide after chickpeas and pigeon peas. Widely produced in Asia and gaining in popularity across Africa, Australia and South America; known for its adaptability and rapid development making it a highly productive summer fallow crop to increase productivity (Appunu et al., 2009). Due to its self-pollinating properties and short lifetime design that facilitates nitrogen fixation; these seeds help increase soil fertility and overall agricultural productivity. *V. radiata* has various morphological traits and growth phases (Sekhon et al., 2006). *V. radiata* has long been recognized for its nutritional quality, adaptability and beneficial contributions to agricultural systems qualities which make it one of the top grain legumes. *V. radiata* is widely recognized for its nutritional benefits, making it a key food component. With 25-28% protein levels-higher than any other legumes-, it provides high quality proteins with balanced amino acid profiles such as lysine, tryptophan and methionine to promote proper brain functioning and general well-being (Sekhon et al., 2006). *V. radiata* contain vitamins C, E and B (thiamine riboflavin niacin folate) as well as potassium magnesium and iron which all play important roles in energy metabolism, immune support and iron absorption processes (Álvarez-Aragón et al., 2023). *V. radiata* is also an excellent source of dietary fiber, boasting approximately 7-7.0% concentration. Fiber helps promote digestive health while controlling blood sugar levels and keeping you feeling satisfied for hours after consumption 1. Being a leguminous crop, Mung bean has the unique capability of fixing atmospheric nitrogen through its association with nitrogen-fixing bacteria, providing improved soil fertility while simultaneously decreasing synthetic fertilizer use, supporting sustainable farming practices and mitigating environmental impacts. This method significantly lowers fertilizer demand while simultaneously supporting sustainable agricultural practices and mitigating environmental damage (Abd-Alla et al., 2014). Drought stress has an adverse impact on Mung bean productivity in areas with unpredictable rainfall patterns or limited water availability, especially where rainfall patterns fluctuate suddenly or water availability is limited (Sekhon et al., 2006).

Many limiting constraints and obstacles affect Mung bean farming's crop growth, development and total productivity. Mung bean is heat sensitive, and heat stress can inhibit various physiological processes that impact photosynthesis, nutrition intake and reproduction development (Amin et al., 2023). High temperatures during blooming and pod-filling stages may result in flower abortion or reduced pod set due to high heat stress; to alleviate it breed for heat tolerance while employing suitable crop management practices like planting at cooler times of the year or planning harvest operations at different intervals can mitigate its negative impacts (Zhang et al., 2008). Drought can negatively impact seedling germination, seedling establishment, flowering and pod development which, ultimately leads to decreased yield and quality yields and quality levels resulting from these adverse impacts of drought stress. Using drought resistant varieties as well as efficient irrigation practices are critical in mitigating their harmful impacts of drought stress and increasing yield and quality as much as possible (Singh et al., 2015). Drought stress poses a threat to crop plants and agricultural systems worldwide, often due to climate change, irregular rainfall patterns or growing water scarcity resulting from climate change or irregular rainfall patterns resulting in water shortage limiting growth and productivity in crop plants (Daryanto et al., 2017). Drought stress occurs when plant tissues don't get sufficient amounts of water needed by their physiological demands; as a result, multiple elements of their physiology, biochemistry and metabolism suffer including reduced photosynthesis production, slower growth development rates, altered water relations with roots as a whole, impaired nutrient uptake as well as hasten senescence rates leading to decreased output among crops plants (Daryanto et al., 2017). Drought stress significantly impacts crop development and output, potentially leading to significant drops in agricultural productivity. Drought occurs when there is insufficient water due to low rainfall levels, excessive evaporation or poor management practices for plants requiring moisture supply here are a few key points regarding drought stress's influence on development and output (Jalal et al., 2023). Photosynthesis has been reduced because of drought. Drought stress decreases water availability for plants, having an immediate and detrimental impact on photosynthesis. Photosynthesis converts sunlight to energy that creates carbohydrates essential to plant development and production; inadequate water availability reduces photosynthetic efficiency leading to decreased production of sugars and other key metabolites essential to their proper growth and maintenance (Uddin et al., 2021). Drought stress interferes with various physiological processes in plants, leading to delayed development and reduced plant height. Drought-stressed plants frequently have smaller leaves with decreased leaf area as well as less shoot and root biomass due to water scarcity constraints which limit organ growth and development (Daryanto et al., 2017).

Organic Fertilizers from natural sources have gained increasing attention as safer and more sustainable alternatives

to synthetic Fertilizers in modern agriculture. Moringa Leaf Extract (MLE), one such natural Fertilizer from Moringa plants with recognized medical and nutritional uses, has bioactive compounds found within its leaves which stimulate plant growth without harming either crops or the environment (Uddin et al., 2021). MLE provides low cost and eco-friendly organic Fertilizer options which have proven outstanding performance when increasing crop output this introduction sets a framework for further investigation of MLE as an organic Fertilizer and its implications in sustainable agriculture (Bañon et al., 2006). Organic Fertilizers play an invaluable role in supporting sustainable agriculture, offering multiple advantages for soil health, environmental sustainability and long-term agricultural output (Assaha et al., 2016). Organic Fertilizers like compost, manure and plant wastes play an integral part in agricultural systems' nutrient cycling processes, enhancement of soil fertility and improve plant health. Plant extracts contain bioactive chemicals with specific physiological impacts on plant growth and development, such as phytohormones, antioxidants, phenolic compounds, flavonoids, terpenoids, alkaloids or others (Abd El-Mageed et al., 2017).

Moringa Leaf Extract (MLE), an organic Fertilizer produced from Moringa tree leaves (*Moringa oleifera*), has gained attention as an organic alternative to synthetic Fertilizers due to its markedly beneficial characteristics for growth promotion and yield enhancement (Rady et al. 2015). MLE contains an abundant supply of key plant nutrients including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). All these components can easily be assimilated by plants for maximum plant growth, development, and productivity (Bañon et al., 2006). MLE provides plant defense responses as well as production of defense chemicals to strengthen plant immunity against natural and man-made threats, such as insects and disease. MLE includes bioactive chemicals which stimulate production of natural defense compounds like phenolic compounds and flavonoids which act as natural defense compounds against pests and diseases; further strengthening immune systems while activating defense pathways and increasing resilience against stressors such as environmental stresses (Younas et al., 2023). MLE has been extensively examined across numerous crops as an organic Fertilizer to combat drought stress tolerance, showing its promise as an organic solution to mitigate water scarcity issues (Uddin et al., 2021). The objective of this study was to identify correct dose of moringa leaf extract for the drought stress mitigation in Mung bean.

MATERIALS AND METHODS

Description of the Study Area

The research was carried out in the Department of Agronomy, University of the Punjab, Lahore field area. This location is situated at latitude of 31.49509592322344 and a longitude of 74.29705455927052. Lahore has a semi-arid climate not receiving enough rainfall to feature the humid subtropical climate. The hottest month is June, where temperatures routinely exceed 45 °C (113 °F). The monsoon season starts in late July, and the wettest months are July and August, with heavy rainfalls and evening thunderstorms with the possibility of cloudbursts and flash floods. The coolest month is January, with dense fog.

Experimental materials and treatments

Treatment combinations

Experiential treatments included various scenarios designed to test the impact of MLE under various soil moisture conditions. The experimental group consisted of plants not treated with MLE application (0x Dilution), while remaining within optimal moisture conditions (100% Field Capacity or FC). In this experiment, we conducted an investigation to study the effects of three MLE concentrations (5x, 10x and 20x) when applied at full FC (Field Capacity). Our main goal was to observe and analyze results relative to MLE use concentration. In this study, we conducted an investigation to examine how plants respond under drought conditions. To simulate drought stress, we applied reduced irrigations for maintaining low field capacity levels: 80% FC (well-irrigated), 50% FC (moderate drought stressed) and 30% FC (severe drought stressed) were chosen so as to mimic water availability constraints in regions with limited access to resources. Additionally, investigation focused on combined therapeutic interventions such as using MLE dilutions with various concentrations (5x, 10x and 20x) along with reduced FC levels (80% FC levels, 50%FC & 30% FC), in conjunction with reductions of soil moisture concentration by MLE concentration potentially revealing cooperative or adverse interactions that might allow tailored agricultural methodologies for geographical areas experiencing water scarcity to be created. The study was consisted of laboratory and field experiments. The laboratory experiment was conducted in completely randomized design with four replications. Whereas the field experiment was conducted in completely randomized design with three replications. Each treatment was randomly assigned in pots in each replication in the experimental field. The size of each experimental pot was 730 cm^2 with three rows spaced at 30 cm between pots. There were 46 experimental pots where experiment was conducted.

Experimental Procedures and Data Collection

Pre-planting laboratory test

For the present study, seeds of a farmers' cultivar were collected from five different farmers who participated in the 2023 cropping season. These collected seeds were mixed in equal proportion to ensure a representative sample for the experiment. Before applying the treatments, the physical quality parameters of the seeds were carefully evaluated to assess their overall quality, including factors such as size, weight, and visual appearance. After the evaluation of physical quality, the seeds' physiological characteristics, particularly seed germination and vigor, were assessed. Seed germination refers to the ability of seeds to develop into viable seedlings under favorable conditions, while seed vigor indicates the overall strength and robustness of the seeds in terms of their potential for successful germination and subsequent growth.

Moringa Leaves extract preparation

The preparation of Moringa leaf extract was conducted using fresh Moringa leaves. The leaves were thoroughly washed to remove any surface contaminants. Subsequently, the washed leaves were frozen at a temperature of 0 ℃ for duration of 24 hrs to preserve their bioactive constituents and prevent enzymatic degradation. After freezing, the leaves were finely ground to a homogeneous paste using a suitable mechanical grinder. The resulting paste was subjected to filtration to separate the liquid extract from the solid residues. The liquid obtained after filtration represented the MLE, containing a concentrated assortment of beneficial phytochemicals and bioactive compounds. In the process of preparing MLE, various dilutions were created to explore its effects at different concentrations. These dilutions, represented as 5 times (5x), 10 times (10x), and 20 times (20x) dilutions, were designed to provide a range of concentrations for experimentation and application. For instance, to make a 5x dilution, 20 ml of the Moringa leaf extract was measured and carefully combined with 100 ml of a suitable liquid medium. The liquid medium used for dilution could be water or another appropriate solvent. By precisely mixing the 20 ml of extract with the 100 ml of liquid, the resulting dilution became five times less concentrated than the original extract. Similarly, to create a 10x dilution, 20 ml of the extract was skillfully blended with 200 ml of the chosen liquid medium. This process led to a dilution that was ten times less concentrated than the undiluted extract. Likewise, for a 20x dilution, 20 ml of the extract was gently mixed with 400 ml of the liquid medium, resulting in a solution that was twenty times less concentrated than the original extract. To ensure the stability and preservation of the extract's potency, it was stored in a cooler environment at a temperature ranging from 10 to 15 ℃. This controlled storage temperature helps to maintain the extract's bioactivity and prevent degradation over time, ensuring the availability of a viable and effective.

Data collection from Pre-planting laboratory test

Seed physical quality test

The physical seed quality test was conducted using 500 g of seeds which were taken from each genotype. Pure seeds, hundred seeds weight and seeds moisture content was determined as per ISTA (2015) procedure as follows:

Pure seed (%) = wt. of pure seed fraction / total working sample wt. X 100

Hundred seeds weight (g)

100 seeds were taken randomly from each treatment in each replication and adjusted to normal moisture content (8 – 9 %), weighted and registered.

Seeds moisture content (%)

5g of seeds from each treatment combination in each replication was taken from the sample seeds, grinded, weighted and poured in a small container with cover and kept in an oven maintained at a temperature of 103 ℃ for a period of 17 hrs. The moisture content of seeds was determined by the following formula (ISTA, 2009).

Moisture content (%) = (M2-M3)/ (M2-M1) × 100

Where;

M1= Weight in grams of container and its cover.

M2= Weight in grams of container, its cover + ground material before drying

M3= Weight in grams of container, its cover + ground material after drying

Seeds germination and vigor

After the physical seed quality test and seed priming had been completed, 400 normal seeds were randomly taken from the total seeds obtained from each genotype for each treatment. The 100 seeds of each treatment in each replication were put on flat tray filled with sterilized sand. The flat tray of 30 cm square was filled to 5 cm depth. Hundred seeds of each treatment were sown in 10 rows at depth of 2-3 cm in one tray filled with sand. The seeds

were kept moist with gently applied water up to the laboratory test completed. The germinated seed counting was started at 5th day after sowing and it was continued up to 10 days. The germination of seeds in each flat tray was counted every day starting the fourth days of sowing. The number of normal and abnormal seedlings was sorted independently in counting. Abnormal seedlings are those badly diseased, discolored or distorted seedlings. The germination and seedlings vigor parameters were measured and registered as follows.

Germination (%) = Total Number of Normal Seedlings /Total Number of Seeds Planted X 100%

Speed of germination

Speed of germination is also another indicator used for assessing the vigor of seeds. 100 seeds were taken from each sample and divided into three replicates and kept at 20℃ temperature for maximum of 14 days in the seed germinator. Germination was evaluated as the percentage of seeds producing normal seedlings as defined by ISTA, Normal seedlings were counted and removed from germination box at each day, and the speed of germination (SG) was be calculated as follows:

SG =Number of Normal Seedlings Days of First Count / Days of First count +…+ Number of Normal Seedlings Days of First Count/Days of Final count

Seedling vigor

Shoot and root length of seedlings (mm)

Shoot and root lengths were determined by measuring average shoot and root length of ten randomly taken seedlings in centimeters after completion of germination period (14 days) from each treatment and replication. The shoot and root lengths of the seedlings were measured from the point of the embryo attachment to the tip of shoot and root. The averages of shoot and root lengths were computed by dividing the total shoot or root lengths by the total number of seedlings on which measurement had been done. The shoot and root lengths were recorded separately and the total seedling length was obtained as the sum of shoot and root lengths.

Seedlings dry weight (g)

Seedling dry weight was determined from ten randomly taken seedlings which were used for measuring shoot and root lengths of seedlings. The seedlings were placed in paper bags, dried at 80 0C for 24 hours, and were weighed (AOSA, 2002). The seedlings were dried and weighed to the nearest milligram and the average seedling dry weight was calculated.

Field experiment

The pots were filled with the soil from the field Area of the Department of Agronomy, which comprises the composition of clay loam. Only 2-3 seedlings were planted in each pot. The transplantation of seedlings was made at the last week of the March as the common practices of seed production. The plants were grown without fertilizer application. Different cultural practices were applied as per the recommendation made for the crop.

Data Collection

Agronomic data collection: the agronomic data was collected from each treatment within each replication as the description is given below.

Days to 50% emergence

Days to emergence was recorded as the number of days from sowing time for each plot when more than 50% of the plants were emerged.

Field emergence Index

Emerged seedlings were counted daily until there has not been further seedlings emergence in the field experiment. The emergence index was calculated as per the procedure of Yang et al. (2005) and modified with the count of seedlings at field emergence as follows:

Field Emergence index = E1/D1 + E2/D2 + …...+ EF/DF

Where: E1 number of seedlings emerged at the first count day, E2 is number of seedlings emerged at the second count day EF is the number of seedlings emerged at the final count, D1, D2 and DF are first, second and final days count, respectively.

Days to 50% flowering

It was determined by counting the number of days after seedling emergence to the period when 50% of the plants in a plot were developing first flower.

Days to 90% maturity

It was taken as the number of days after the seeds were sown to the period when 90% of the plants in a plot were attained physiological maturity and ready for harvest as revealed by change in the foliage and pod color and seed

hardening in the pods.

Plant height (cm)

It was recorded at physiological maturity by measuring the main stem height from the ground up to the canopy height using a ruler from randomly selected five plants per plot from central rows and the average plant height was recorded in centimeters.

Number of pods per plant

It was recorded from ten randomly selected plants from the net plot area at harvest and the average result was taken as the number of pods per plant.

Number of seeds per pod

It was determined from randomly selected five pods from ten plants used for pod number count and the average number was taken as number of seeds per pod.

Number of seeds per plant

It was recorded by counting each number of seed per plant from the selected five plants and the average number was taken as a number seeds per plant.

100 Seeds weight (g)

100 seeds were randomly taken from each treatment in each replication and were adjusted to normal moisture content (8 – 9 %), then weighted and recorded the result in grams.

Seed yield (kg^{-1})

It seeds were taken from the middle two rows of each treatment in each replication and air-dried to adjust at the optimum seed moisture content, then the seed yield weight was measured using sensitive balance.

Statistical Analysis

Statistical analysis was done by using Statistix 8.1 software for Analysis of variances. Tukey's HSD (Highest Significant Difference Test) was used for analysing the level of significance among treatment and pairwise comparisons**.**

RESULTS

Agronomic parameters

The agronomic parameters of Mung bean were significantly influenced under drought conditions and foliar spray of MLE. The interaction between MLE and Mung bean under drought stress has shown a significant impact on the plant's biomass production (Tab. 1). MLE, a bio stimulant, has shown a progressive impact on the various parameters to the plant.

Germination percentage (%)

The ANOVA (Tab. 1) results for germination percentage values indicate non-significant effects of the MLE x Drought factor (F = 0.28 p = 0.9762), suggesting that there is no significant difference in germination percentage values with respect to MLE and Drought.

Shoot Dry Weight (gm)

The ANOVA (Tab. 2) results for shoot dry weight values indicate non-significant effects of the MLE x Drought factor (F = 1.96 p = 0.0782), suggesting that there is no significant difference in shoot dry weight values with respect to MLE & Drought. It is evident from the Fig 1 the treatment MLE (5) + FC (100) has shown non-significant result in shoot dry weight of the plant with the control (MLE (0) + FC (100)). The treatment with MLE (0) with drought condition FC (30) had a minimum shoot dry weight of 3.64 g While the plants treated with MLE (5) with drought condition FC (100) has shown the 62% increase in the shoot dry weight i.e., (MLE (5) + FC (100)). MLE (5) + FC (100) have shown non-significant results with all the other treatments.

Table 1: ANOVA for Germination percentage (%) of Mung plant with effect of treatments of MLE, Drought, MLE × Drought.

Treatment	DF	SS	MS	F	P
MLE	3	522.96	174.32	1.58	0.2141
Drought	3	659.01	219.671	1.99	0.1357
MLE × Drought	9	276.36	30.707	0.28	0.9762
Error	32	3537.42	110.544		
Total	47	140.51			
Grand Mean 88.98					CV 11.82

Table 2: ANOVA for Shoot dry weight (g) of Mung plant with effect of treatments of MLE, Drought, MLE × Drought.

Treatment	DF	SS	MS	F	P
MLE	3	50.062	16.6875	14.96	0
Drought	3	35.062	11.6875	10.48	0.0001
MLE × Drought	9	19.688	2.1875	1.96	0.0782
Error	32	35.697	1.1155		
Total	47	140.51			
Grand Mean 8.5808					CV 12.31

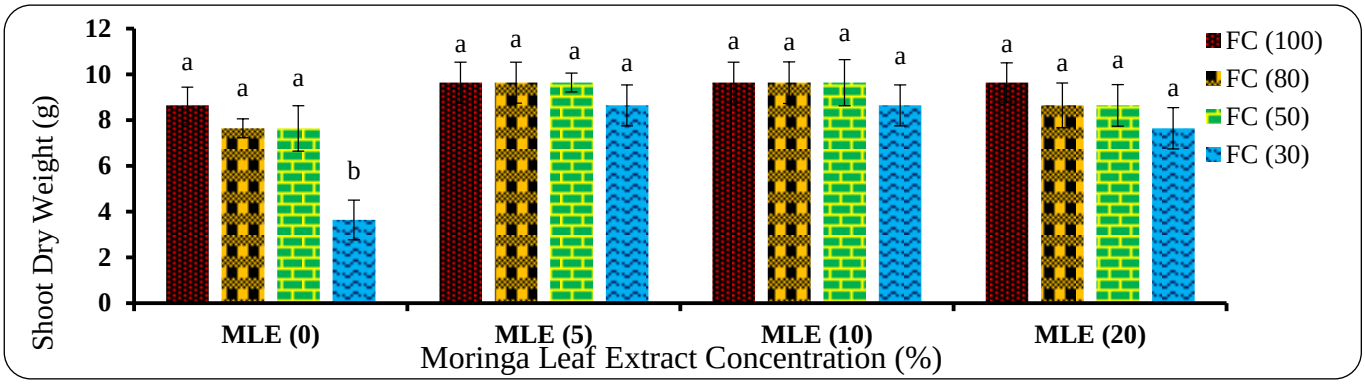

Figure 1. Effect of different MLE conc. on the shoot dry weight of the Mung Bean plant under drought condition.

Root Dry weight (gm)

The ANOVA (Tab. 3) results for root dry weight values indicate significant effects of the MLE × Drought with MLE and Drought values (F = 4.8, p = 0.0004), Suggesting that there is significant difference in Root dry weight values between MLE & drought. It is evident from the Fig. 2 the treatment MLE (5) + FC (100) has shown significant result in root dry weight of the plant with the Control (MLE (0) + FC (100)). The treatment with MLE (0) with drought condition FC (30) had a minimum root dry weight of 0.534 gram. While the plants treated with MLE (5) with drought condition FC (100) has shown the 57% increase in the root dry weight i.e., (MLE (5) + FC (100)).

Table 3. ANOVA for Root dry weight (g) of Mung plant with effect of treatments of MLE, Drought, MLE × Drought.

Treatment	DF	SS	MS	F	P
MLE	3	0.92181	0.30727	67.99	0
Drought	3	0.39804	0.13268	29.36	0
MLE × Drought	9	0.19531	0.0217	4.8	0.0004
Error	32	0.14461	0.00452		
Total	47	1.65977			
Grand Mean 1.0862					CV 6.19

Number of pods per plant

The ANOVA (Tab. 4) results for no. of pods per plant values indicate significant effects of the MLE × Drought with MLE and Drought values (F = 4.51, p = 0.0007), suggesting that there is significant difference in no. of pods per plant values between MLE & drought. It is evident from the Fig. 3 the treatment MLE (5) + FC (80) has shown significant result in no. of pods per plant with the Control (MLE (0) + FC (100)). The treatment with MLE (0) with drought condition FC (30) had a minimum no. of pods of 2 pods per plant. While the plants treated with MLE (5) with drought condition FC (80) has shown the 60% increase in the root dry weight i.e., (MLE (5) + FC (80).

The ANOVA (Tab. 5) results for germination percentage values indicate non-significant effects of the MLE x Drought factor (F = 1.85 p = 0.097), suggesting that there is no significant difference in germination percentage values with respect to MLE & Drought.

It is evident from the Fig. 4 the treatment MLE (5) + FC (100) has shown non-significant result in 100 seed weight of the plant with the Control (MLE (0) + FC (100)). The treatment with MLE (0) with drought condition FC (30) had a

minimum 100 seed weight of 2.388 g While the plants treated with MLE (5) with drought condition FC (100) has shown the 60% increase in the root dry weight i.e., (MLE (5) + FC (100)).

Table 4. ANOVA for Number of pods per plant of Mung plant with effect of treatments of MLE, Drought, MLE × Drought.

Treatment	DF	SS	MS	F	P
MLE	3	321.583	107.194	105.01	0
Drought	3	93.583	31.194	30.56	0
MLE × Drought	9	41.417	4.602	4.51	0.0007
Error	32	32.667	1.021		
Total	47	489.25			
Grand Mean 8.4583					CV 11.95

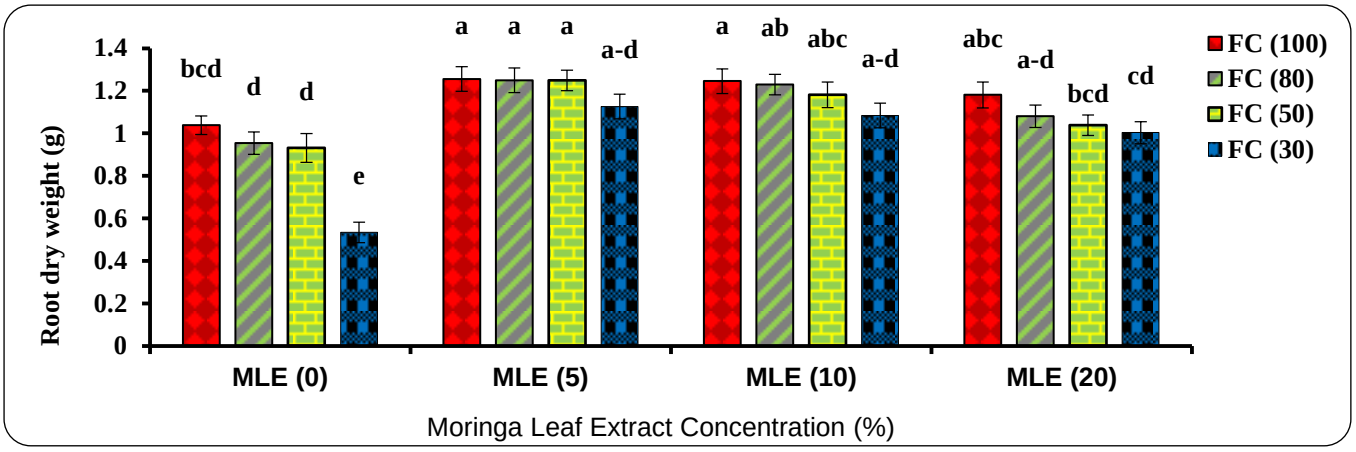

Figure 2. Effect of different MLE conc. on the root dry weight of the Mung Bean plant under drought condition 100 seed weight

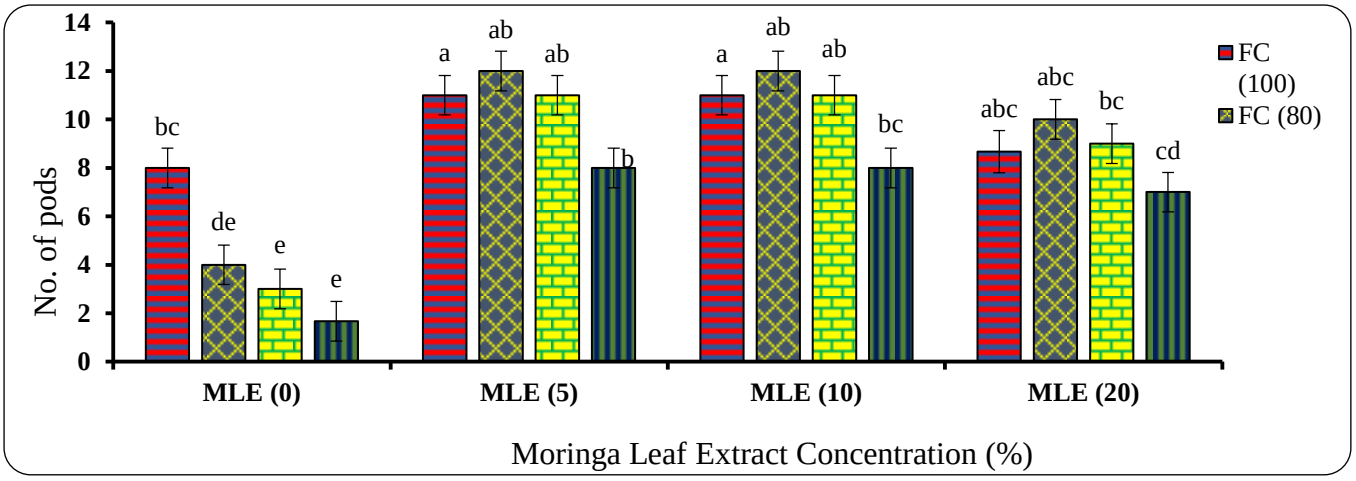

Figure 3. Effect of different MLE conc. on the no. of pods per plant of the Mung Bean plant under drought condition 100 seed weight

Table 5. ANOVA for 100 seed weight of Mung plant with effect of treatments of MLE, Drought, MLE × Drought.

Treatment	DF	SS	MS	F	P
MLE	3	33.2913	11.0971	54.43	0
Drought	3	29.0335	9.6778	47.47	0
MLE×Drought	9	3.3958	0.3773	1.85	0.097
Error	32	6.5241	0.2039		
Total	47	72.2448			
Grand Mean 4.3472					CV 10.39

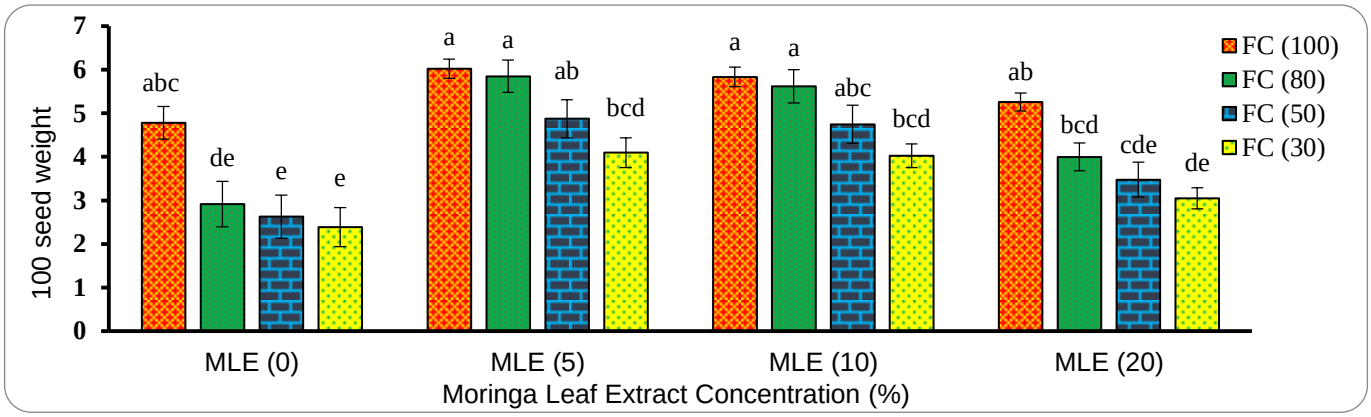

Figure 4. Effect of different MLE conc. on the 100 seed weight of the Mung Bean plant under drought condition

Biological Yield

The ANOVA (Tab. 6) results for biological yield values indicate non-significant effects of the MLE x Drought factor (F = 1.85 p = 0.097), suggesting that there is no significant difference in biological yield values with respect to MLE & Drought. It is evident from the Fig. 5 the treatment MLE (5) + FC (100) has shown non-significant result in biological yield of the plant with the Control (MLE (0) + FC (100)). The treatment with MLE (0) with drought condition FC (30) had a minimum biological yield of 4.57 g^{-2}. While the plants treated with MLE (5) with drought condition FC (100) has shown the 73% increase in biological yield i.e., (MLE (5) + FC (100).

Table 6. ANOVA for Biological Yield of Mung plant with effect of treatments of MLE, Drought, MLE × Drought.

Treatment	DF	SS	MS	F	P
MLE	3	317.718	105.906	57.55	0
Drought	3	187.892	62.631	34.04	0
MLE ×Drought	9	30.45	3.383	1.84	0.0993
Error	32	58.884	1.84		
Total	47	594.944			
Grand Mean 13.229					CV 10.25

Grain Yield

The ANOVA (Tab. 7) results for germination percentage values indicate non-significant effects of the MLE x Drought factor (F = 1.84 p = 0.0993), suggesting that there is no significant difference in germination percentage values with respect to MLE & Drought. It is evident from the Fig. 6 the treatment MLE (5) + FC (80) has shown significant result in grain yield of the plant with the Control (MLE (0) + FC (100)). The treatment with MLE (0) with drought condition FC (30) had a minimum biological yield of 0.39 gm-2. While the plants treated with MLE (5) with drought condition FC (80) has shown the 93% increase in the grain yield i.e., (MLE (5) + FC (80)).

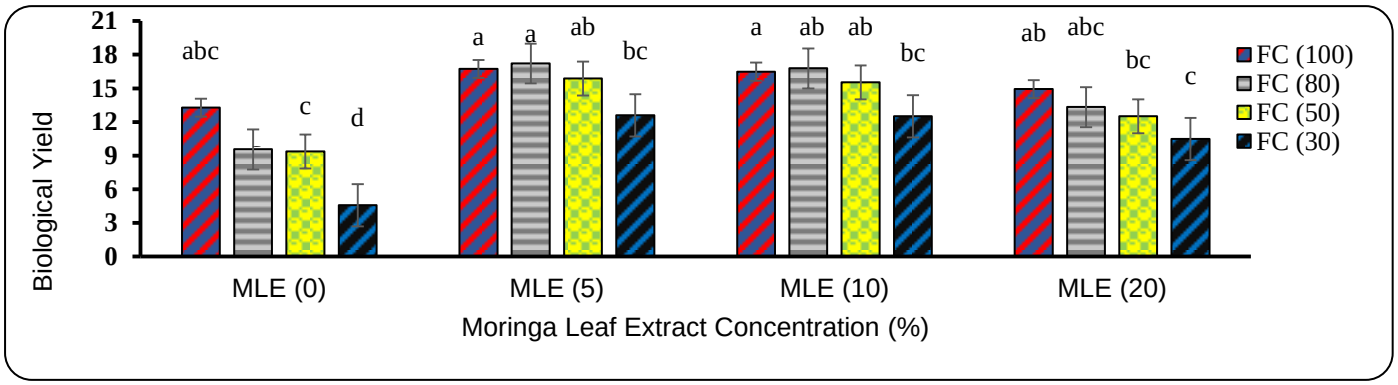

Figure 5. Effect of different MLE conc. on the Biological Yield of the Mung Bean plant under drought condition.

Table 7. ANOVA for Grain Yield of Mung plant with effect of treatments of MLE, Drought, MLE × Drought.

Treatment	DF	SS	MS	F	P
MLE	3	98.156	32.7188	88.18	0
Drought	3	54.104	18.0345	48.61	0
MLE × Drought	9	13.007	1.4452	3.89	0.002
Error	32	11.873	0.371		
Total	47	177.14			
Grand Mean 3.5613					CV 17.10

Harvest Index

The ANOVA results (Tab. 8) for harvest index values indicate significant effects of the MLE * Drought with MLE and Drought values (F = 4.23, p = 0.0011), suggesting that there is significant difference in harvest index values between MLE & drought.

It is evident from the Fig. 7 the treatment MLE (5) + FC (100) has shown non-significant result in biological yield. of the plant with the Control (MLE (0) + FC (100)). The treatment with MLE (0) with drought condition FC (30) had a minimum biological yield of 8.307%. While the plants treated with MLE (5) with drought condition FC (80) has shown the 77% increase in the harvest index i.e., (MLE (5) + FC (80).

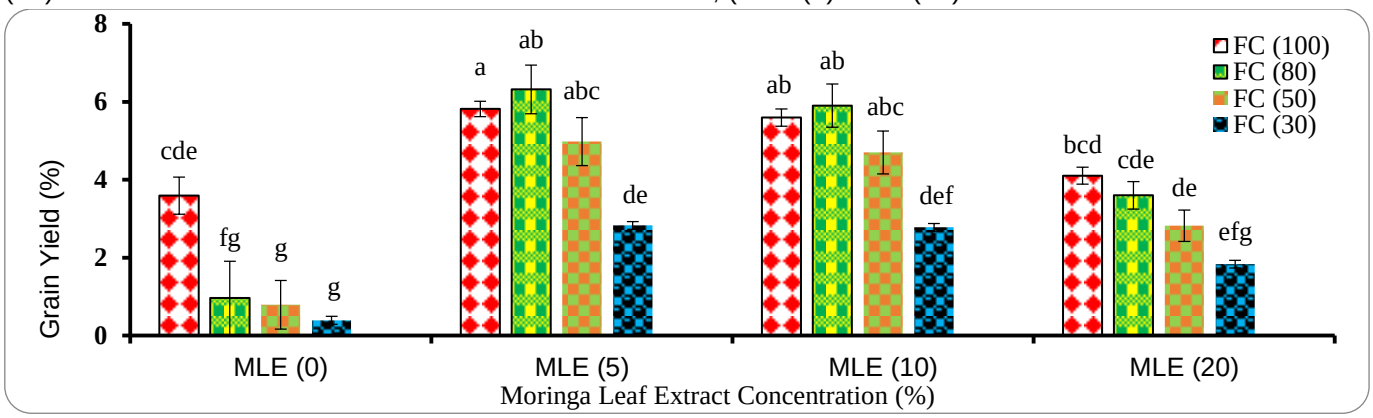

Figure 6. Effect of different MLE conc. on the grain yield of the Mung Bean plant under drought condition

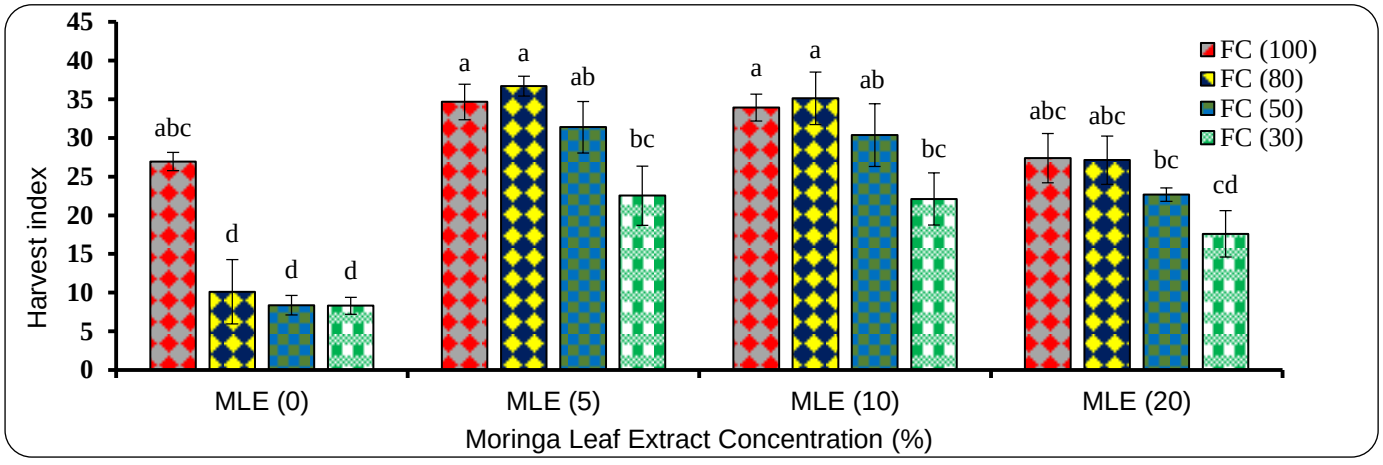

Figure 7. Effect of different MLE conc. on the Harvest Index of the Mung Bean plant under drought condition

DISCUSSION

Agriculture research must recognize the considerable significance of water soil deficit, which exerts an immense effect on Mung bean plant growth and progression. Drought's effects can be observed through reduced fresh and dry weight measurements in shoots and roots of Mung bean specimens experiencing stress compared to control group specimens. Empirical evidence regarding drought impacts aligns closely with Assaha et al. (2016) which highlighted how an inadequate supply of water inhibited both aboveground and underground structures found on

Huckleberry (*Solanum scabrum Mill*) plants. This decrease can be explained by metabolic disturbances triggered by stress and the subsequent production of reactive oxygen species (ROS). Producing ROS leads to an observable reduction in cell division, elongation, turgor volume and overall growth. Furthermore, this impairment has a direct bearing on photosynthetic capacities of plant leaves; furthermore, there could be hindrance for water/nutrient transport via blocked translocation vessels, according to Bañon et al. (2006).

Table 8. ANOVA for Harvest Index (%) of Mung plant with effect of treatments of MLE, Drought, MLE × Drought

Treatment	DF	SS	MS	F	P
MLE	3	2448.61	816.202	69.02	0
Drought	3	1141.52	380.506	32.18	0
MLE × Drought	9	449.68	49.964	4.23	0.0011
Error	32	378.41	11.825		
Total	47	4418.21			
Grand Mean 24.711					CV 13.92

Moringa oleifera leaf extract used as foliar spray on Mung bean plants experiencing drought stress leads to significant improvements in various growth parameters and physio-chemical characteristics, even under unfavorable water scarcity conditions. Ali et al. (2011) also observed this result with increasing drought stress causing *Zea mays* plants' fresh and dry weights (shoots and roots) to decline relative to control plants (in terms of fresh weight and dry weight loss). This observation aligns well with these studies' observations that showed significant enhancement in various growth parameters. This research supports Ali et al. (2011) work where increased drought stress led to reduced shoot and root weights relative to control plants not subjected to any drought stress exposure (control plants).

Moringa oleifera's remarkable capacity to boost plant growth can be explained by its abundant protein content which plays a vital role in producing protoplasm. Furthermore, essential minerals like potassium, calcium, magnesium as well as natural antioxidant compounds such as ascorbic acid flavonoids phenolics and carotenoids contribute further to this substance's extraordinary growth enhancing capabilities (Singh et al., 2023).

Balakumbahan and Rajamani (2010) and Prabu et al. (2019) conducted separate studies demonstrating the efficacy of Moringa leaf extract at various concentrations on basil and senna plants with similar success; both researchers achieved excellent results. Noteworthy is the observation that the 2% concentration showed greater effectiveness when compared with its 4% counterpart, leading to significant enhancement of several growth parameters including plant height, leaf number and area, weight, pod number, branch number and yield. Our current research offers further proof of Moringa leaf extract's beneficial influence on Mung bean growth, evident through multiple indicators such as shoot and root development, pod number and weight of 100 seeds.

MLE treatments on Cucurbita pepo plants demonstrated significant increases in fruit yield over its control group, evidenced by (Abusuwar and Abohassan, 2017) and (Elzaawely et al., 2017) studies conducted using MLE. Effectiveness of MLE as an approach for increasing agricultural productivity has long been established by notable investigations conducted by Abusuwar and Abohassan (2017) as well as Elzaawely et al. (2017) investigations.

Attributes that shape mung bean yield include pod quantity, 100 seed weight, biological yield and Moringa leaf extract concentration are essential in shaping its final outcome. As evidenced by previous research conducted with various crops such as onions, kidney beans and tomato; higher concentrations of Moringa Leaf Extracts correlate positively with increased forage yield correlated to an increase in fruit yield associated with MLE can be attributed to enhanced growth traits as well as bio stimulants present within it.

Furthermore, studies demonstrate a direct relationship between concentration-dependent increases of inorganic elements and growth hormones and subsequent increases in growth and forage production. This trend can be observed among plant species such as alfalfa, clitoria, and mung bean; with plants exposed to treatments with higher concentration showing significant enhancements in growth; notable improvements were noted across various growth parameters.

The interrelation of drought conditions, organo-mineral Fertilizer applications, degree of irrigation (DI), and seasons has serious ramifications for various aspects such as dry matter accumulation, harvest index (HI), leaf area development in cucumber plants. Organo-mineral Fertilizer (OMF) usage produced varied results most significantly crop production occurred when full irrigation was implemented along with OMF application; its influence has also been extensively documented and widely acknowledged scientific literature.

Under deficit irrigation conditions when plants experience stress, OMF becomes more apparent, leading to reduced dry matter content, (HI), and leaf area; consistent with Abd El-Mageed and Semida (2015) research findings. Overall, this examination confirms the significant effect water scarcity has had on Mung bean plant development and productivity and how Moringa leaf extract helps further this development through increased productivity; further evidenced in previous research conducted in this field of research.

CONCLUSION AND FUTURE PERSPECTIVES

Overall, this research marks an essential advancement towards an enhanced understanding of Moringa Leaf Extract's (MLE) ability to mitigate drought stress effects in *Vigna radiata* agriculture. Mung bean (*Vigna radiata*) has long been recognized for its nutritional and adaptability properties in agricultural systems, yet this crop still faces challenges caused by drought stress in regions with unpredictable weather patterns. MLE with its abundance of biologically active plant compounds helps crops overcome water scarcity issues by complying with sustainable agriculture principles and improving crop performance.

Investigation into various MLE dilutions, with particular attention given to its fivefold dilution, has yielded evidence of its remarkable growth-promoting qualities. This selected dilution stands out as an exceptional bio stimulant, having significant impacts on key indicators of plant growth such as root weights and shoot weights, pod yields, rates of germination and quality metrics of seed yield. MLE exerts an undeniably powerful effect at various stages of growth, from germination through vegetative growth, reproduction and pod production. It is well known for enhancing crop productivity under resource-scarce conditions evidenced by impressive increases such as 60% increase in seed number in plants exposed to drought conditions.

Investigation of molecular signaling cascades associated with this phenomenon is crucial in order to discover molecular communications at a cellular level. Field trials at various agro ecological niches offer significant promise to determine ecological resilience and practicality at the MLE-drought stress interface. Enhancement of application techniques including selection of appropriate dosage, timing and frequency as well as evaluation of potential synergies between other agronomic interventions represents numerous opportunities for future scientific investigation. These efforts, supported by empirical observations and quantitative measurements, could significantly transform crop management practices, leading to greater sustainability and resilience of agricultural systems in response to rising climate variability.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this research.

COMPETING OF INTEREST

The authors declare no competing interests.

REFERENCES

Abd-Alla, M.H., Issa, A.A., Ohyama, T., 2014. Impact of harsh environmental conditions on nodule formation and dinitrogen fixation of legumes. Advances in Biology And Ecology of Nitrogen Fixation 9, 1.

Abd El-Mageed, T.A., Semida, W.M., 2015. Effect of deficit irrigation and growing seasons on plant water status, fruit yield and water use efficiency of squash under saline soil. Scientia Horticulturae 186, 89-100.

Abd El-Mageed, T.A., Semida, W.M., Rady, M.M., 2017. Moringa leaf extract as biostimulant improves water use efficiency, physio-biochemical attributes of squash plants under deficit irrigation. Agricultural Water Management 193, 46-54.

Abusuwar, A.O., Abohassan, R.A., 2017. Effect of Moringa olifera leaf extract on growth and productivity of three cereal forages. Journal of Agricultural Science 9, 236-243.

Ali, M., Abbas, A., Awan, S., Jabran, K., Gardezi, S., 2011. Correlated response of various morpho-physiological characters with grain yield in sorghum landraces at different growth phases. Journal of Animal and Plant Sciences 21, 671-679.

Álvarez-Aragón, R., Palacios, J.M., Ramírez-Parra, E., 2023. Rhizobial symbiosis promotes drought tolerance in *Vicia sativa* and *Pisum sativum*. Environmental and Experimental Botany 208, 105268.

Amin, F., Ullah, S., Saud, S., Ihsan, M.Z., Hassan, S., Kumar, S., Nawaz, T., Harrison, M.T., Liu, K., Khan, I., 2023. Hydrothermal time analysis of mung bean (*Vigna radiata* (L.) Wilczek) seed germination at different water potential and temperatures. South African Journal of Botany 157, 447-456.

Appunu, C., N'zoue, A., Moulin, L., Depret, G., Laguerre, G., 2009. *Vigna mungo*, *V. radiata* and *V. unguiculata* plants sampled in different agronomical–ecological–climatic regions of India are nodulated by *Bradyrhizobium*

yuanmingense. Systematic and Applied Microbiology 32, 460-470.
Assaha, D.V.M., Liu, L., Ueda, A., Nagaoka, T., Saneoka, H., 2016. Triveni enterprises. Journal of Environmental Biology 37, 107-114.
Balakumbahan, R., Rajamani, K., 2010. Effect of biostimulants on growth and yield of Senna (*Cassia angustifoliavar* KKM. 1).
Bañon, S., Ochoa, J., Franco, J., Alarcón, J., Sánchez-Blanco, M.J., 2006. Hardening of oleander seedlings by deficit irrigation and low air humidity. Environmental and Experimental Botany 56, 36-43.
Daryanto, S., Wang, L., Jacinthe, P.-A., 2017. Global synthesis of drought effects on cereal, legume, tuber and root crops production: A review. Agricultural Water Management 179, 18-33.
Elzaawely, A.A., Maswada, H.F., El-Sayed, M., Ahmed, M.E., 2017. Phenolic compounds and antioxidant activity of rice straw extract. International Letters of Natural Sciences 64.
Jalal, A., Rauf, K., Iqbal, B., Khalil, R., Mustafa, H., Murad, M., Khalil, F., Khan, S., da Silva Oliveira, C.E., Teixeira Filho, M.C.M., 2023. Engineering legume for drought stress tolerance: Constraints, accomplishments, and future prospects. South African Journal of Botany 159, 482-491.
Prabu, S.L., Umamaheswari, A., Puratchikody, A., 2019. Phytopharmacological potential of the natural gift *Moringa oleifera* Lam and its therapeutic application: An overview. Asian Pacific Journal of Tropical Medicine 12, 485-498.
Sekhon, H., Bains, T., Kooner, B., 2006. Grow summer mungbean for improving crop sustainability, farm income and malnutrition, I International Conference on Indigenous Vegetables and Legumes. Prospectus for Fighting Poverty, Hunger and Malnutrition 752, pp. 459-464.
Singh, G., Kumar, D., Sharma, P., 2015. Effect of organics, biofertilizers and crop residue application on soil microbial activity in rice–wheat and rice-wheat mungbean cropping systems in the Indo-Gangetic plains. Cogent Geoscience 1, 1085296.
Singh, P., Saini, N., Bhola, L., Mishra, P., Aamir, M., 2023. Crosstalk of biostimulants with other signaling molecules under metal stress, Biostimulants in Alleviation of Metal Toxicity in Plants. Elsevier, pp. 469-509.
Uddin, S., Ullah, S., Nafees, M., 2021. Effect of seed priming on growth and performance of *Vigna radiata* L. under induced drought stress. Journal of Agriculture and Food Research 4, 100140.
Younas, M., Rasool, M.H., Khurshid, M., Khan, A., Nawaz, M.Z., Ahmad, I., Lakhan, M.N., 2023. *Moringa oleifera* leaf extract mediated green synthesis of silver nanoparticles and their antibacterial effect against selected gram-negative strains. Biochemical Systematics and Ecology 107, 104605.
Zhang, Y.F., Wang, E.T., Tian, C.F., Wang, F.Q., Han, L.L., Chen, W.F., Chen, W.X., 2008. *Bradyrhizobium elkanii*, *Bradyrhizobium yuanmingense* and *Bradyrhizobium japonicum* are the main rhizobia associated with *Vigna unguiculata* and *Vigna radiata* in the subtropical region of China. FEMS Microbiology Letters 285, 146-154.