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Investigating the Effects of *Azadirachta Indica* Leaf Extract on Drought Tolerance and Productivity of Mung Bean

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Abstract

Mung beans, an economically and nutritionally valuable leguminous crop, adapt well to various environmental conditions. Neem leaf extract (NLE) boasts bioactive compounds in crops. Different studies demonstrate a positive interaction between its use in drought conditions and increased plant growth, biomass production and stress tolerance, providing sustainable agricultural practices and crop resilience. NLE played significant roles in the experiments to check different parameters i.e., germination rate, shoot and root dry weight, no. of pods per plant, 100 seed weight, Biological Yield, Grain Yield and harvest index. In germination Rate, NLE5-FC100 treatment demonstrated the highest germination rate at 100%; on the other hand, NLE20-FC30 achieved 80.95% germination. In Shoot Dry Weights, NLE5-FC100 treatment resulted in the highest average shoot dry weight at 10.643, while NLE10-FC30 had the lowest at only 4.6443 grams per square meter. In Root Dry Weight, NLE5-FC100 treatment had the highest dry root weight at 1.3436; NLE10-FC30 had 0.6288. NLE5-FC100 treatments had the highest number of pods per plant (12.33), while NLE10-FC30 treatments produced three pods or fewer per plant (3.33). In 100 Seed Weight, NLE5-FC100 treatment recorded the highest 100 seed weight at 7.33, while NLE20-FC30 produced 3.21 seeds per plant. In Biological Yield, NLE5-FC100 treatment had the highest biological yield at 20.165; while NLE10-FC30 produced the lowest yield with 6.155. In Grain Yield, NLE5-FC100 treatment yielded the highest grain yield at 8.1178 while NLE10-FC30 produced only 0.7969 of grain yield. In Harvest Index, NLE5-FC100 treatment had the highest harvest index at 40.371, while NLE5-FC30 achieved 11.08 as its minimum index value. This study concluded that 5x Dilution leaf extract possesses stronger bio stimulant capabilities than other Dilutions; thus, enabling Mung bean seeds to produce more seeds and lessen drought stress effects.

Keywords: Leaf extract, Field capacity, *Vigna radiata*, Legumes, Self pollination

INTRODUCTION

Mung (*Vigna radiata*), commonly called mung bean or green gram, is an influential legume crop widely grown for its seeds. As part of the Fabaceae family and subfamily Faboideae classification system, these beans belong to the subfamily Faboideae for classification. Mung plants exhibit indeterminate growth characteristics for self-pollination purposes with $2n=22$ diploid chromosome numbers; therefore, it demonstrates indeterminate characteristics about indeterminate self-pollination capability within its own [1].

Mung (*Vigna radiata*) nutrition is often an integral research component; here is an in-depth explanation [2]. Mung beans provide an abundant source of carbs (a source of energy for our body), including simple sugars like glucose and fructose and complex ones like starch and fiber. Mung beans contain essential amino acids for tissue health and repair; their protein consumption stimulates growth stimulation. Mung beans have exceptionally low-fat content, mostly consisting of unsaturated fatty acids such as linoleic and oleic acids, which play an integral role in various physiological processes within our bodies. Mung beans provide numerous essential micronutrients such as C and K vitamins as well as B-complex ones, including Thiamin (B1), Riboflavin (B2), Niacin (B3), and Folate (B9), pyridoxine (B6) which plays essential roles in energy metabolism, immunity support, and overall well-being. Mung bean cultivation can present several production constraints which impede its yield and overall productivity, including pests and diseases which threaten its yield and productivity. Farmers often encounter difficulties when cultivating Mung Bean: susceptibility can be an ongoing threat when farming this crop, with insects like aphids, thrips, and pod borers damaging crops significantly and leading to decreased yield [3].

Abiotic factors are essential in shaping crops such as Mung (*Vigna radiata*). Drought and salinity pose particular threats that threaten its productivity and survival, respectively. Drought, which refers to insufficient water availability, has become one of the major environmental challenges globally. An extended water deficit disrupts Mung's physiological processes. It causes decreased photosynthesis production and disruptions to her hormone signaling pathways, ultimately resulting in reduced photosynthesis and hormone pathways disruptions. Mung plants exposed to drought stress often experience stunted growth and decreased flower and pod production and yields. Furthermore, reactive oxygen species (ROS) accumulation creates further havoc by damaging cells within its tissues, further aggravating plant health issues [4].

Drought is one such environmental stressor that adversely impacts plant development of Mung Bean plants as well as overall plant growth and development. Water shortage can severely limit crop germination and root development. Leaves may wilt early while flowers and pods drop more quickly all contributing to reduced yield. In regions with limited water resources, developing strategies to increase Mung Bean drought tolerance and boost productivity during water deficit conditions becomes vitally important. Establishing sustainable, cost-effective ways of combatting biological and abiotic stresses is crucial if Mung Bean production is to remain steady and increase, guaranteeing food security and economic well-being for farmers and communities that rely on it [3]. Salinity, is another critical abiotic factor limiting Mung production. Soil salinity occurs from accumulations of soluble salts like sodium chloride in the root zone, leading to increased osmotic stress and ion toxicity for plant roots. High salinity levels interfere with Mung's water uptake, interfering with their balance and absorption of essential nutrients and causing physiological disorders, including ionic imbalances, reduced chlorophyll content, and impaired enzyme activities. Salinity-induced oxidative stress damages cell membranes, proteins, and nucleic acids, resulting in cell dysfunction and reduced growth and yield in Mung crops, necessitating drought-tolerant varieties and sustainable agricultural practices for optimal production in affected regions [5].

Biotic factors are integral to Mung (*Vigna radiata*) production by directly impacting plant growth and development, particularly pests and diseases contributing to yield losses. At various stages of development, insect pests commonly attack Mung. For example, pod borer (*Helicoverpa armigera*) larvae feed on developing pods resulting in physical damage and reduced seed viability. In contrast, Aphids (*Aphis craccivora*) and whiteflies (*Bemisia tabaci*) feed off plant sap, leading to stunted growth, leaf curling, and the spread of viral diseases. *Melanagromyza obtusa* larvae burrow deep within stems, causing lodging, further compounding crop damage by these pests. Not only can they decrease productivity by lodging stems and stem leaves, but they can act as vectors transmitting viral and bacterial diseases, further compounding damage to crops [6].

Mung production can also be threatened by various fungal, bacterial, and viral diseases; one such threat is powdery mildew caused by *Erysiphe polygons*. This disease targets leaves, pods, and stems to disrupt photosynthesis, reducing production while decreasing yields significantly. Damping-off disease caused by *Rhizoctonia solani* and Fusarium wilt caused by *Fusarium oxysporum* is responsible for seedling mortality and stand reduction, respectively. Yellow Mosaic Virus (YMV) and Mungbean Yellow Mosaic India Virus (MYMIV), two

viruses spread via viral transmission, can cause yellowing of leaves, reduced pod development, or crop failure. Mung growers must identify any factors threatening crop health to create effective pest and disease management strategies, including using resistant varieties, cultural practices, biological control methods, and any necessary pesticide applications. Doing this effectively enables Mung farmers to reach greater crop health while realizing higher yields [7].

Improving *Vigna radiata* productivity requires an integrated approach encompassing agronomy, genetics, and crop management. A primary strategy to increase Mung productivity involves selecting high yielding drought tolerant varieties through conventional or biotechnological breeding approaches; researchers have achieved success producing cultivars that exhibit enhanced yield potential as well as resistance against drought stress, such as early maturity rates that increase pod number per pod and seed count as well as superior water-use efficiency resulting in greater productivity under difficult environmental conditions [8].

Neem leaf extract appears to help mitigate drought stress through multiple mechanisms, including decreasing water loss through stomatal regulation, acting as an antioxidant against ROS production, and inducing stress-responsive gene expression. All these activities combine into improved drought tolerance in plants treated with the extract, suggesting its use could provide an eco-friendly and sustainable method for increasing crop productivity in water-limited environments. Nonetheless, further investigation will need to define specific molecular pathways involved with its efficacy for different plant species across environments and climate conditions [7].

Present study was design to investigate the impact of various concentrations of NLE on plant growth and development under conditions of limited soil moisture, commonly referred to as drought conditions. *Azadirachta indica*, an impressive plant with impressive nutritional and medicinal benefits, has received much recognition. Our study's primary goal was to observe and critically analyze outcomes related to NLE usage concentration. At present, this research set out to understand how plants respond physiologically and biochemically when subjected to drought conditions.

MATERIALS AND METHODOLOGY

Study Area

The investigation was conducted within the field area of the Department of Agronomy at the University of the Punjab. The geographical coordinates of this location are determined to be at latitude of 31.49509592322344 and a longitude of 74.29705455927052.

Experimental Design and Planting material

Seeds collected from farmers' cultivars were obtained from an eclectic group of ten farmers participating actively in cropping season 2023. The experimental group consisted of plants which did not receive any NLE applications (0x), yet were managed under optimal moisture conditions (100% Field Capacity or FC). We conducted this experimental investigation to explore the impacts of three concentrations of NLE at full FC (Field Capacity). These concentrations included 5x, 10x, and 20x their initial application levels. To simulate conditions of drought stress, we employed various reduced irrigation techniques that led to lower field capacity levels. At this stage of research, three levels of irrigation were selected as examples: 80% field capacity (representing well-irrigated conditions), 50% field capacity (representing moderate drought stress) and 30% field capacity (representing severe drought stress). We selected these levels so as to simulate limitations on water availability typically experienced in regions with limited resources [9].

Furthermore, our study sought to assess the effects of combined therapeutic interventions in areas facing water scarcity. More specifically, we conducted analyses utilizing NLE dilutions with different concentrations (5x, 10x and 20x) combined with reduced FC levels (80% FC / 50% FC and 30% FC respectively) along with soil moisture reduction techniques to investigate any cooperative or adverse interactions that might assist us in creating tailored agricultural methodologies suitable for such regions.

Preparation of Neem Leaves extracts (NLE):

The preparation of Neem leaves extract was conducted using fresh leaves of Neem. After washing procedure leaves were under goes to a 24 hour freeze process at 0°C in order to preserve bioactive components found within them and prevent any possible breakdown due to enzyme activity [10]. Following the freezing step, they were carefully ground into a uniform paste using an appropriate mechanical grinder. Several different concentrations of NLE were carefully prepared as dilutions so as to explore its various impacts at differing concentrations. A 5x, 10x and 20x dilution was prepared by carefully mixing 20 mL of NLE with 100, 200 and 400 mL of an appropriate liquid medium respectively and, it was stored at temperatures ranging between 10-15 °C in order to preserve its bioactivity over an extended period and prevent its degradation; thus, ensuring an affordable product.

***In vitro* Parameter Analysis**

Seed Quality test

Evaluation of seed quality was accomplished using 500 grams sample for each genotype under investigation, according to International Seed Testing Association's (ISTA)

procedure of 2015. Measurements such as purity seeds weight and moisture content were recorded following specific steps outlined by ISTA (2015):

$$\text{Pure seed (\%)} = \frac{\text{Weight of Pure seed Fraction}}{\text{Weight of total working sample}} \times 100$$

Hundred Seeds weight

One hundred seeds were randomly selected from each treatment in each replication and adjusted to an ideal moisture content range between 8-9%. Their weights were then recorded [11].

Seeds moisture content

5g of seeds from each treatment combination within each replication were carefully chosen from each group and ground, weighed and placed into individual small containers with covers to maintain consistent conditions in an oven set at 103 °C for 17 hours before moisture content analysis using formulae outlined by International Seed Testing Association guidelines (ISTA) 2009 [12].

$$\text{Moisture content (\%)} = \frac{M2-M3}{M2-M1} \times 100$$

M1 indicates the weight in grams of both the container and cover; M2 represents this same measurement combined with any ground materials. M3 indicates the weight (in grams) of an entire container including its cover and any ground materials contained there following drying process.

Seeds germination

400 seeds showing normal characteristics from each genotype for each treatment were randomly selected from all treatment locations for every replication, in each replication 100 seeds from that treatment were carefully placed onto flat trays filled with sterilized sand; similarly a rectangular tray measuring 30 cm on either side was uniformly filled to depth of 5 cm with substance; finally one hundred seeds from each treatment were planted into 10 rows at depths between 2-3 cm within one tray which was completely filled with sterilized sand to test success of results. Germinated seed counting began five days after sowing and continued until 10th day after sowing. Finally, parameters related to both seedling germination and seedling vigor measurements and recording were performed and recorded accordingly [13].

$$\text{Germination (\%)} = \frac{\text{Total Number of Normal Seedlings}}{\text{Total Number of Seeds Planted}} \times 100\%$$

Seedling Vigor

The shoot and root lengths of the seedlings were assessed by measuring the average length of the shoots and roots of ten randomly selected seedlings in centimeters. The dry

weight of seedlings (measured in grams) was assessed by selecting ten seedlings at random [14].

***In vivo* Experiment**

The pots were filled with soil taken from the field Area of the Department of Agronomy, known for its clay loam composition. A limited number of 2-3 seedlings were carefully placed and cultivated within individual pots.

Collection of Data

Agronomic data collection involved the systematic gathering of data pertaining to various agronomic factors. This data was collected from each treatment within each replication, adhering to a specific protocol.

Days to 50 % emergence

The duration of emergence, referred to as "days to emergence," was meticulously documented by measuring the number of days that transpired from the initial sowing of seeds for each experimental plot until more than half of the plants had successfully emerged from the soil [15].

Days to 50% flowering

The determination of the time interval from seedling emergence to the point at which 50% of the plants within a given plot exhibited the initial signs of flower development was achieved through a process of day-counting [16].

Days to 90% maturity

The parameter measured in this study was the duration, in days, from the time the seeds were planted until 90% of the plants in a specific area reached physiological maturity. Physiological maturity was determined by observing changes in the color and condition of the foliage and pods, as well as the hardening of the seeds within the pods [17].

Plant Height

The measurement of physiological maturity was conducted by assessing the height of the main stem, from the ground to the canopy, using a ruler. This measurement was taken on five randomly selected plants from each plot, specifically from the central rows. The resulting plant heights were recorded in centimeters, and the average height was calculated.

No. of pods per plant

The number of pods per plant was determined by collecting data from ten plants randomly selected within the net plot area at the time of harvest. The average value obtained from these measurements was considered as the representative number of pods per plant.

No. of seeds per pod

The number of seeds per pod was determined by randomly selecting five pods from a total of ten plants. The average number of seeds per pod was then calculated.

No. of seeds per plant

The data was collected by meticulously tallying the number of seeds produced by each plant within the chosen sample of five plants. Subsequently, the average number of seeds per plant was calculated by dividing the total number of seeds by the number of plants surveyed.

100-Seed weight

In order to conduct a comprehensive analysis, a total of 100 seeds were selected at random from each treatment within each replication. These seeds were subsequently subjected to a process of normalization, ensuring that their moisture content reached a standard level of 8-9%. Following this adjustment, the seeds were carefully weighed, and the recorded measurements were expressed in grams.

Seed yield

Seeds were carefully selected from the middle two rows of each treatment within each replication. These seeds were then subjected to air-drying in order to achieve the optimal moisture content for seed preservation. Subsequently, the weight of the seed yield was accurately measured using a highly sensitive balance.

Statistical Analysis

Statistical analysis was performed by using **Statistix 8.1** software for Analysis of variances. Fisher's LSD (Least Significance Difference Test) was used for analysing the level of significance among treatment and pairwise comparisons ($P \leq 0.05$).

RESULTS AND DISCUSSION

Germination rate

The treatment involving NLE 5 at Field Capacity 100 (NLE5-FC100) demonstrated the highest recorded value i.e., 100% amongst all treatments, signifying its potential to enhance the targeted response. Conversely, the treatment involving NLE20 at Field Capacity FC30 exhibited the lowest recorded value i.e., 80.95%, highlighting the variability in response observed across treatments (Fig 1).

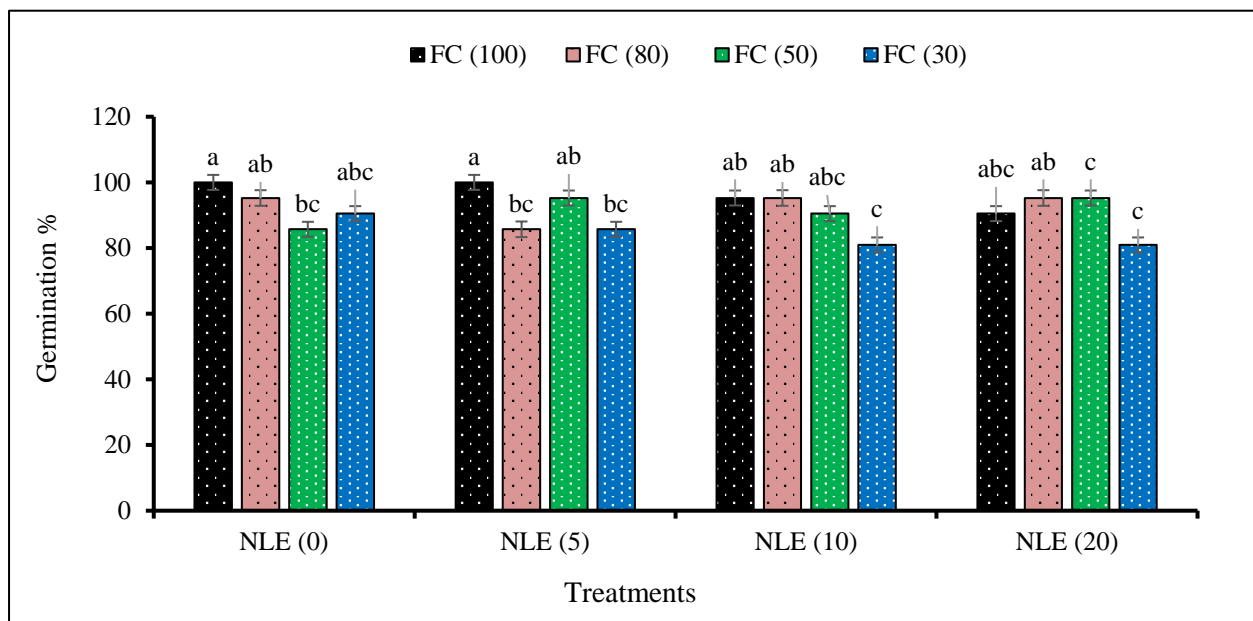


Fig 1: Effect of Neem Leaf Extract (NLE) on the Germination % of *Vigna radiata* Seeds. Where 0, 5, 10 and 20 times(x) diluted NLE applied. While FC (100, 80, 50 and 30) is represent the Pots irrigation field capacity. All values represent mean \pm SE, Bars with different letters suggest significant differences as per Tukey's LSD test ($P \leq 0.05$).

Shoot dry weight

It is evident from the Fig 2 that treatment using Neem Leaf Extract 5 (NLE) in combination with Field Capacity 100 (FC) has yielded statistically significant outcomes in comparison to the Control (no NLE + FC100) group. The treatment involving NLE 5 at Field Capacity 100 (NLE5-FC100) demonstrated the highest recorded value i.e., 10.643 amongst all treatments, signifying its potential to enhance the targeted response. Conversely, the treatment involving NLE10 at Field Capacity FC30 exhibited the lowest recorded value i.e., 4.643, highlighting the variability in response observed across treatments.

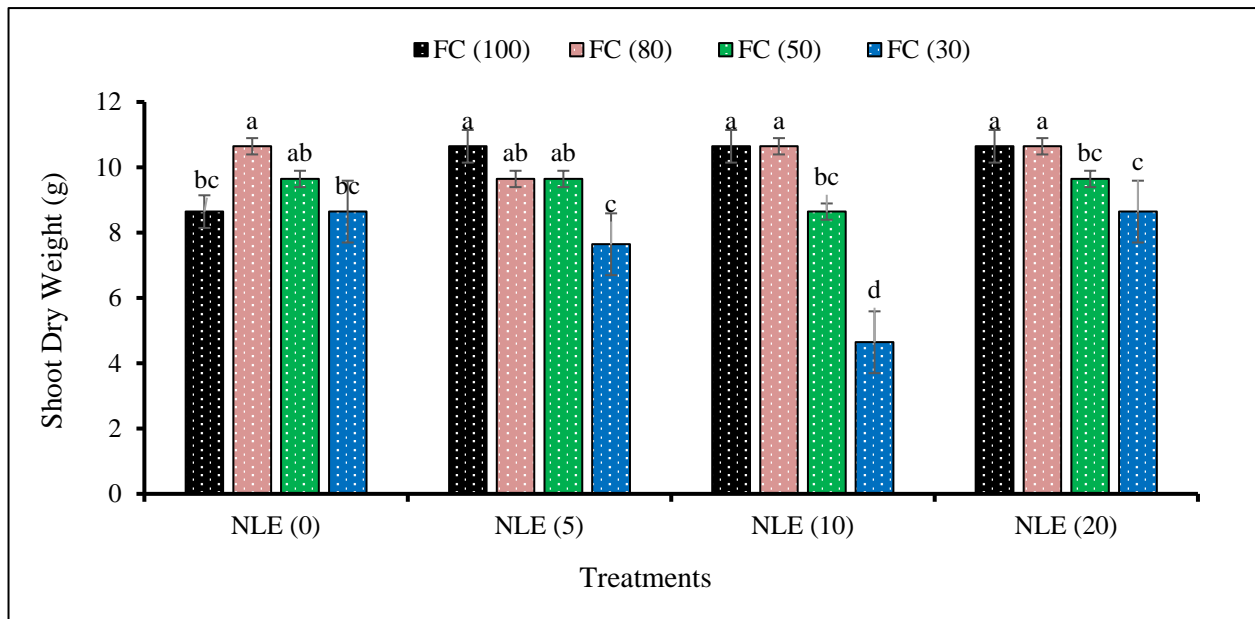


Fig 2: Effect of Neem Leaf Extract (NLE) on the shoot dry weight of *Vigna radiata* plant. Where 0, 5, 10 and 20 times(x) diluted NLE applied. While FC (100, 800, 50 and 30) is represent the Pots irrigation field capacity. All values represent mean \pm SE, Bars with different letters suggest significant differences as per Tukey's LSD test ($P \leq 0.05$).

Root dry weight

It is evident from the Fig 3 that treatment using Neem Leaf Extract 5 (NLE) in combination with Field Capacity 100 (FC) has yielded statistically significant outcomes in comparison to the Control (no NLE + FC100) group. The treatment involving NLE 5 at Field Capacity 100 (NLE5-FC100) demonstrated the highest recorded value i.e., 1.3436 amongst all treatments, signifying its potential to enhance the targeted response. Conversely, the treatment involving NLE10 at Field Capacity FC30 exhibited the lowest recorded value i.e., 0.6288, highlighting the variability in response observed across treatments.

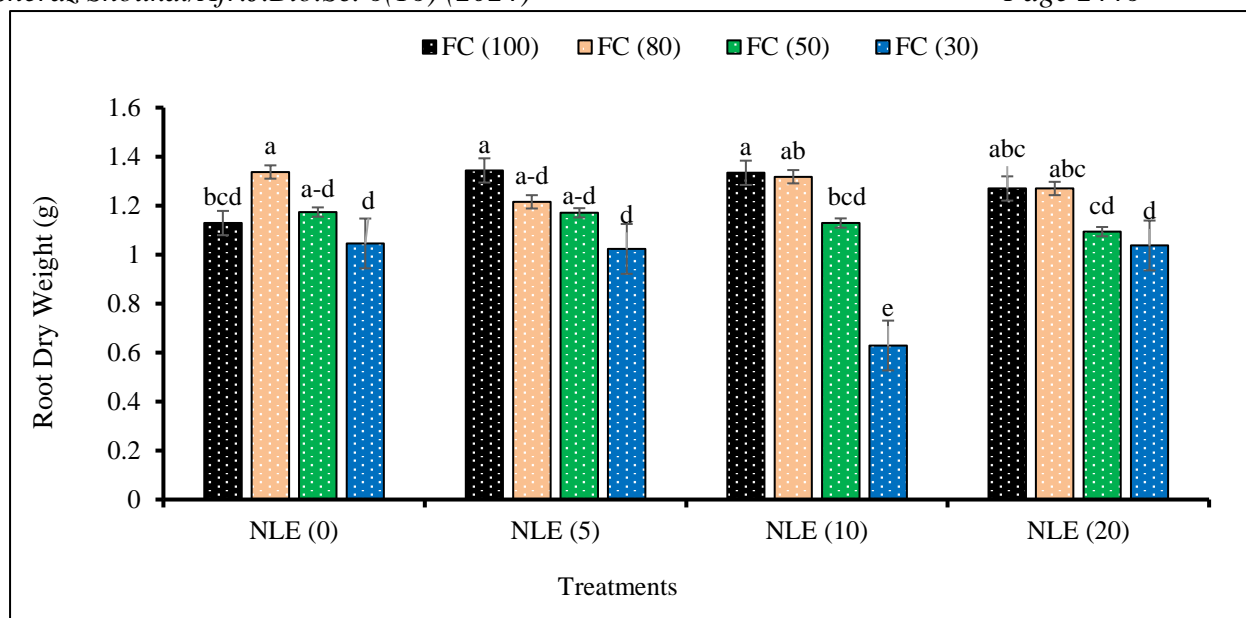


Fig 3: Effect of Neem Leaf Extract (NLE) on the Root dry weight of *Vigna radiata* plant. Where 0, 5, 10 and 20 times(x) diluted NLE applied. While FC (100, 800, 50 and 30) is represent the Pots irrigation field capacity. All values represent mean \pm SE, Bars with different letters suggest significant differences as per Tukey's LSD test ($P \leq 0.05$).

No. of pods per plant

The treatment using Neem Leaf Extract 5 (NLE) in combination with Field Capacity 100 (FC) has yielded statistically significant outcomes in comparison to the Control (no NLE + FC100) group. The treatment involving NLE 5 at Field Capacity 100 (NLE5-FC100) demonstrated the highest recorded value i.e., 12.33 amongst all treatments, signifying its potential to enhance the targeted response. Conversely, the treatment involving NLE10 at Field Capacity FC30 exhibited the lowest recorded value i.e., 3, highlighting the variability in response observed across treatments (Table 1).

100 Seed weight

It is evident from the Table 1 that treatment using Neem Leaf Extract 5 (NLE) in combination with Field Capacity 100 (FC) has yielded statistically significant outcomes in comparison to the Control (no NLE + FC100) group. The treatment involving NLE 5 at Field Capacity 100 (NLE5-FC100) demonstrated the highest recorded value i.e., 7.33 amongst all treatments, signifying its potential to enhance the targeted response. Conversely, the treatment involving NLE20 at Field Capacity FC30 exhibited the lowest recorded value i.e., 3.21, highlighting the variability in response observed across treatments.

Table 1: Effect of Neem Leaf Extract (NLE) on the No. of Pods, per plant 100 Seed Weight (g), Biological Yield (%), Grain Yield (%) of *Vigna radiata* plant. Where 0, 5, 10 and 20 times(x) diluted NLE applied. While FC (100, 80, 50 and 30) is represent the Pots irrigation field capacity. All values represent mean differences as per Tukey’s LSD test ($P \leq 0.05$).

Treatment	Field Capacity															
	100	80	50	30	100	80	50	30	100	80	50	30	100	80	50	30
	No. of Pods per plant				100 Seed Weight (g)				Biological Yield (%)				Grain Yield (%)			
NLE 0	9.33	8	8.66	4.33	5.42	7.15	5.08	3.61	14.33	17.13	14.77	11.1	4.56	5.15	3.96	1.41
NLE 5	12.33	9	7.33	3.33	7.32	6.01	5.09	3.58	20.16	15.72	14.16	9.74	8.17	4.86	3.35	1.07
NLE 10	12	8.66	7.33	3	7.05	6.55	5.05	3.25	19.59	17.07	13.10	6.15	7.61	5.10	3.33	0.88
NLE 20	11	8	8	4.33	5.97	6.23	4.43	3.21	17.82	16.40	17.17	12.93	5.91	4.48	5.19	0.79

Biological Yield

The treatment using Neem Leaf Extract 5 (NLE) in combination with Field Capacity 100 (FC) has yielded statistically significant outcomes in comparison to the Control (no NLE + FC100) group. The treatment involving NLE 5 at Field Capacity 100 (NLE5-FC100) demonstrated the highest recorded value i.e., 20.165 amongst all treatments, signifying its potential to enhance the targeted response. Conversely, the treatment involving NLE10 at Field Capacity FC30 exhibited the lowest recorded value i.e., 6.155, highlighting the variability in response observed across treatments (Table 1).

Grain Yield

Table 1 show that treatment using Neem Leaf Extract 5 (NLE) in combination with Field Capacity 100 (FC) has yielded statistically significant outcomes in comparison to the Control (no NLE + FC100) group. The treatment involving NLE 5 at Field Capacity 100 (NLE5-FC100) demonstrated the highest recorded value i.e., 8.1178 amongst all treatments, signifying its potential to enhance the targeted response. Conversely, the treatment involving NLE10 at Field Capacity FC30 exhibited the lowest recorded value i.e., 0.7969, highlighting the variability in response observed across treatments.

Harvest Index

It is evident from the Fig 4 that treatment using Neem Leaf Extract 5 (NLE) in combination with Field Capacity 100 (FC) has yielded statistically significant outcomes in comparison to the Control (no NLE + FC100) group. The treatment involving NLE 5 at Field Capacity 100 (NLE5-FC100) demonstrated the highest recorded value i.e., 40.371 amongst all treatments, signifying its potential to enhance the targeted response. Conversely, the treatment involving NLE5 at Field Capacity FC30 exhibited the lowest recorded value i.e., 11.08, highlighting the variability in response observed across treatments.

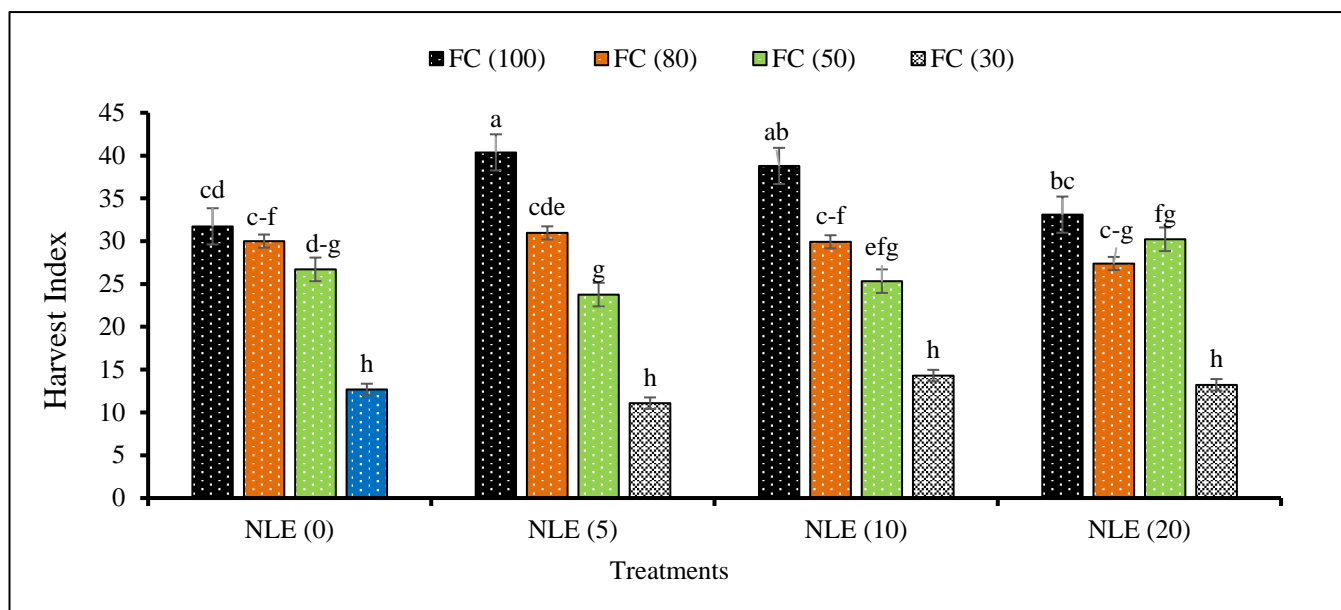


Fig 4: Effect of Neem Leaf Extract (NLE) on the Harvest index of *Vigna radiata*. Where 0, 5, 10 and 20 times(x) diluted NLE applied. While FC (100, 800, 50 and 30) is represent the Pots irrigation field capacity. All values represent mean \pm SE, Bars with different letters suggest significant differences as per Tukey's LSD test ($P \leq 0.05$).

DISCUSSION

The present study sought to establish the potential role of Neem leaf extract in mitigating drought-induced stress on Mung beans (*Vigna radiata*). Results of the current research were then subject to comparative analyses with similar research published elsewhere highlighting similarities with similar observations recorded prior.

Germination rates play a vital role in a plant's ability to establish it under difficult circumstances, and our investigation showed that presence of water deficit conditions had an important impact on Mung bean seeds' germination rates. Alam et al. (2015) found similar results, noting how water deficiency caused an adverse impactful on seed germination processes [18]. Dawood et al. (2014) reported an observed reduction in germination rate as a consequence of limited water availability due to drought stress, reflecting Mung bean's susceptibility [19].

Shoot and root dry weights serve as reliable indicators of plant growth in conditions of stress, including drought. Our findings reveal a marked reduction in both shoots and roots when exposed to limited water availability consistent with research conducted by [19] as well as [20] which found negative impacts of water scarcity on metabolism and biomass as reported by [19, 20]; however the addition of NLE resulted in an increase in dry weights which corresponds with positive findings reported when studying tomato plants [21].

Assessing reproductive success and productivity of plants involves considering various criteria, such as number of pods per plant, 100 seed weight, biological yield and grain yield [22]. These parameters give valuable insights into a plant's overall performance in terms of reproductive output and productivity, with our research showing a decrease when exposed to drought stress conditions. This observation aligns with a growing consensus among scholars that water scarcity wreaks havoc on plant reproductive processes and crop productivity [18]. Recent studies have established that using NLE has the power to enhance plant productivity as evidenced by improvements in various parameters, particularly tomatoes as was documented by [23]. This positive impact was witnessed across various crops including tomatoes.

Harvest index provides insights into resource distribution between harvested components like grains and the remaining parts of plants, such as leaves [24]. Our study's findings highlight a decrease in harvest index when exposed to water deficiency situations. This observation supports the notion that drought-induced stress reallocates resources from reproductive organs towards survival mechanisms and stress coping strategies. Neem Leaf Extract was shown to increase harvest index values and therefore could potentially have a favorable influence in resource allocation. Similar findings when conducting their experiment using water stressed canola plants treated with exogenous Ascorbic Acid (AsA) was also observed [23].

This study sought to assess the benefits of NLE on alleviating drought stress on Mung bean plants. NLE ability to relieve stress is evidenced in its beneficial impact on various parameters, including shoot and root dry weights, chlorophyll content, osmoregulation, total phenolics content, total proteins produced and antioxidant enzyme activities. These findings provide intriguing evidence on the efficacy of NLE as an aid against stress. However, additional investigation must take place in order to gain a complete understanding of these impacts and apply these findings across agricultural settings more broadly. This research contributes significantly to expanding knowledge in plant stress responses while providing important implications for agricultural practices aimed at strengthening crop resilience against harsh environments.

CONCLUSION

Mung beans (*Vigna radiata*), due to their resilience under various environmental circumstances, boast both economic and nutritional significance. Utilizing Neem Leaf Extract (NLE), known for its abundance of bioactive components found within it and obtained from *Azadirachta indica* tree leaves, offers an interesting solution. Studies conducted over recent

years have uncovered an intriguing synergy between NLE treatment and improvements to plant growth, biomass output, and stress tolerance of Mung beans, along with environmental-friendly farming methods and crop improvement. This relationship provides an attractive pathway toward environmentally friendly farming methods and crop improvement.

This study focused on key variables which capture key characteristics of plant performance while investigating their complex interdependencies such as NLE beans and Mung beans. This research offers exciting new perspectives. The 5x Dilution NLE's impressive performance boost is evidence of its ability to mitigate drought stress effects. Researching the molecular details behind NLE ingredients and Mung bean physiology could shed more light on their specific associations. Extending experimental parameters to incorporate various stresses and crop types may provide a clearer view of NLE's applicability, leading to greater understanding about its applicability in agricultural contexts. Harnessing bioactive substances like NLE may transform crop management techniques, increasing food security while contributing towards environmental sustainability as sustainable agriculture practices gain ground.

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