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Exploring salinity effects on moth beans in response to physiological parameters

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ABSTRACT

The moth bean (*Vigna aconitifolia*) is a resilient leguminous crop, primarily cultivated in arid and semi-arid regions due to its remarkable drought tolerance and nutritional value. Known for its ability to thrive in harsh environments, the moth bean is an important source of protein and essential nutrients, playing a vital role in the diet and economy of communities in these regions. The study aimed to understand how varying levels of salinity (ranging from 0 mM to 500 mM) affect the growth and physiological processes of this leguminous crop. Morphological parameters, including root length, shoot length, and the number of secondary roots, were analyzed, alongside biochemical markers such as chlorophyll content, protein levels, and enzyme activity. The results showed a significant decline in root and shoot lengths, as well as a reduction in secondary roots, with increasing salinity. Biochemical analyses revealed decreases in chlorophyll content and protein levels, while enzyme activity initially increased at moderate salinity levels before sharply declining at higher concentrations. These findings highlight the detrimental effects of salinity on moth bean growth and suggest potential strategies for enhancing salinity tolerance in agricultural practices. The study underscores the importance of developing salinity-resistant crops to sustain productivity in arid and semi-arid regions.

Keywords: salinity, moth beans, morphology, biochemical parameters, chlorophyll, protein, enzymes.

INTRODUCTION

Particularly in semi-arid and dry places, where water is scarce and soil is salty, salinity is one of the most abiotic stresses impacting agricultural output globally. Agricultural output is negatively impacted by salinity stress, which is defined as excessive soil or water salt concentrations that stunt plant growth. Climate change, unsustainable irrigation practices, and groundwater overextraction are predicted to exacerbate salinity, a problem that impacts 20% of irrigated land and 2% of dryland agriculture globally (Gayacharan et al., 2023). Leguminous crops are salt-sensitive. They improve soil fertility and fix atmospheric nitrogen, making them essential to sustainable agriculture. Moth beans (*Vigna aconitifolia*) are a popular leguminous crop due to their flexibility, nutritional content, and drought resistance. Because they constitute a staple meal, moth beans are grown in dry and semi-arid Africa and India. Moth beans can survive in dry environments, but salt damages them. Rising soil salinity threatens moth bean harvests and food security in many regions (Gaur et al., 2023).

Salinity mostly affects plants through hormonal changes, ion poisoning, and osmotic stress. The soils with high salt concentrations prevent plants from absorbing water, causing osmotic stress, turgor pressure, stomatal closure, and photosynthetic impairment decrease. Too much sodium (Na^+) and chloride (Cl^-) in plant tissues can affect enzyme activity and cellular balance, causing ion toxicity (Harsh et al., 2016). Salinity hinders plant absorption of essential nutrients, such as potassium (K^+), calcium (Ca^{2+}), and magnesium

(Mg^{2+}), leading to nutritional imbalances. Biochemical and morphological features show how salinity affects plants. Short shoots, roots, and secondary roots can result from salt stress. This indicates the plant's decreased soil nutrition and water absorption (Sharma et al., 2021). Plant function depends on chlorophyll, protein, and enzyme concentrations, which are biochemically changed by salinity stress. Salt stress reduces chlorophyll, which decreases photosynthetic potential and plant growth. Plant growth and production are also affected by metabolic protein and enzyme levels as well as stress responses. Understanding how salt affects moth beans is crucial to mitigating its negative impacts and ensuring sustainable production. Moth beans are essential to dry and semi-arid agriculture.

Previous research on salinity stress in leguminous crops, including moth beans, has shown similar trends of growth inhibition and physiological alterations. Gaur et al. (2023) reported that increasing salinity significantly reduced root and shoot length in moth beans, which is consistent with the findings presented in this paper. Their study also observed a decline in chlorophyll content and protein levels, aligning with the biochemical trends identified in this research. Similarly, Sachdeva et al. (2016) highlighted that moth bean genotypes exhibited varying levels of salt tolerance, with certain genotypes maintaining better enzyme activity under moderate salinity stress. The conducted study supports this by showing an initial increase in enzyme activity at lower salinity levels (50–100 mM) before a sharp decline at higher concentrations. Additionally, research by Sharma et al. (2021) on other leguminous crops, such as chickpeas and lentils, demonstrated that prolonged exposure to salinity leads to oxidative stress and reduced photosynthetic efficiency, comparable to the trends observed in moth beans. However, differences in tolerance levels may be attributed to genetic variations among species. These comparisons reinforce the detrimental impact of salinity on moth beans while highlighting the potential for breeding salt-tolerant varieties to enhance crop resilience in saline environments.

Salinity affects moth beans, an important crop in dry and semi-arid environments, therefore understanding it is crucial. Salinity exacerbates heat, dryness, and poor soil. Increased soil salinity will reduce moth bean yields, endangering smallholder farmers' food security. Moth beans are important, although their salt stress response has been researched less than in the case of other leguminous crops. Salt effects on moth beans are unknown, compared to lentils, chickpeas, and soybeans. This knowledge vacuum has prevented the plans to boost the salt tolerance of moth beans and adapt their agricultural methods to changing climates. Few studies have integrated the morphological and biochemical responses of moth bean to salt stress. As climate change intensifies and unsustainable agricultural practices continue, soil salinity is becoming a major threat to crop productivity. Research on salt-tolerant plants is crucial for ensuring food security and sustainable agriculture in the future. Exploring genetic modifications, breeding programs, and soil management strategies can help mitigate this challenge. An effective salt stress management plan for moth beans demands a thorough understanding of how salinity affects crop development and biochemistry. This approach will help us understand the salinity resistance, physiological processes and breed harder varieties of moth beans. Salinity is becoming a greater problem in moth bean-growing areas, thus studies on how salinity affects moth bean morphology and biochemistry are needed now. This study will assist researchers in reducing moth bean salt damage by researching how they react physiologically to salt.

Objective

This study examined how salinity affects the morphology and biochemistry of moth bean (Vigna aconitifolia). This study examined how salt levels affect root length, shoot length, and secondary root amount as the growth of moth beans progressed. Salinity should also be examined in relation to physiological biochemical indicators of the plant, including chlorophyll, protein, and enzyme activity. This study used 50–500 mM salinity treatments on a freshwater-treated control set of plants. Experimental measurements included secondary root count, shoot and root length, and other morphological parameters. Biochemical experiments assessed chlorophyll, protein, and enzyme levels in salinity-treated plants. To identify the trends in moth bean salt stress responses, the results of this study were statistically analyzed to determine their significance. The study aimed to illuminate the physiological mechanisms for salt tolerance of moth beans and create the framework for salt-resistant crop development.

Hypothesis

This study found that high salinity impairs moth bean metabolism and development. In high salinity, moth beans may shrink their roots, shoots, and secondary roots. Salt-induced physiological stress may reduce moth bean chlorophyll, protein, and enzyme activity. Salinity reduces plant water and nutrient absorption, creating osmotic stress, ion toxicity, and nutritional imbalances. Damage to moth bean shape and biochemistry is predicted to limit growth and productivity. This trial was expected to show how salinity affects moth beans and whether they can tolerate high salt levels. To conclude, moth bean salt effects must be studied to solve arid and semi-arid soil salinization issues. This study explored the morphological and biochemical reactions of moth beans to salt to understand their physiological mechanisms and design more resistant crops.

MATERIALS AND METHODS

Plant material and growth conditions

The study utilized legume moth beans (*Vigna aconitifolia*), a crop renowned for its adaptability to arid and semi-arid regions. These beans were chosen for their inherent resilience and ability to grow in saline environments, making them an ideal candidate for studying the impact of salinity on plant growth and physiology. To ensure the reliability of the experiment, seeds were procured from a certified agricultural seed dealer. This step guaranteed genetic purity and uniformity, thereby providing a consistent basis for analyzing the morphological and biochemical responses of the plants under controlled salinity conditions. Spraying the seeds with 0.1% (w/v) mercuric chloride surface-sterilized them for three minutes. After that, they were repeatedly cleaned with distilled water to remove impurities (Tiwari et al., 2018). This sterilization was necessary to prevent fungal and bacterial contamination during germination and development. After sterilization, the seeds were planted in plastic pots filled with a sterilized 3:1 loamy soil-to-sand soil mixture. Moth beans prefer well-drained soil; therefore, this combination was created with that in mind. A growing room controlled the atmosphere for the containers. To simulate external temperature variations, the chamber was kept at 25 °C during the day and 20 °C at night. The cool white fluorescent lights provided 250 μmol m^{-2} s^{-1} of light with a photoperiod of 16 hours of light and 8 hours of darkness. The experiment maintained 60% relative humidity. The ideal growing conditions for moth beans guided the selection of these settings, which allowed isolating salinity treatment growth variations from environmental variables.

Table 1. Fresh weight

Conc.	Pot 1	Pot 2	Pot 3
Control	1.36 (gm)	2.24 (gm)	3.1 (gm)
50 mM	5.5	3.5	3.6
100 mM	3.2	3.2	3.6
200 mM	3.1	3.7	4.3
400 mM	1.4	1.4	1.1
500 mM	1.2	1.3	1.2

Salinity treatment

Different amounts of sodium chloride (NaCl) solutions were employed to simulate soil salinity. Salinity treatments were 50, 100, 200, and 500 mM, equivalent to NaCl values as mentioned in Figures 1–2 and Tables 1–2. These values showed a very mild to extremely severe salinity gradient. A control group was irrigated with freshwater (0 mM NaCl) for comparison. The salinity treatment began two weeks after seed germination, providing seedlings time to establish before stress. NaCl solutions were made from analytical-grade sodium chloride in distilled water (Priya et al., 2015). Each pot received 100 mL of the appropriate NaCl solution every three days to maintain salt levels. Every period, the control group received the same amount of freshwater. All experimental groups received the same salt level using this method.

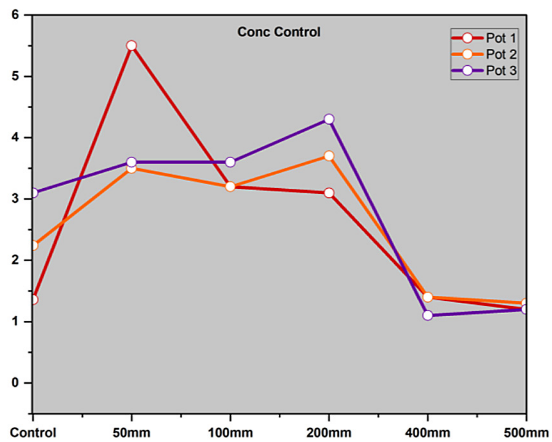

Figure 1. Graphical representation of fresh weight

Table 2. Dry weight-(25 AUGUST) (time-4:11PM)

Conc.	Pot 1	Pot 2	Pot 3
Control	1.2 gm	1 gm	1.3 gm
50 mM	1.8	1.5	1.2
100 mM	1	1.3	1.2
200 mM	1.1	1.1	1
400 mM	1.2	1	0.8
500 mM	1.1	1	1.1

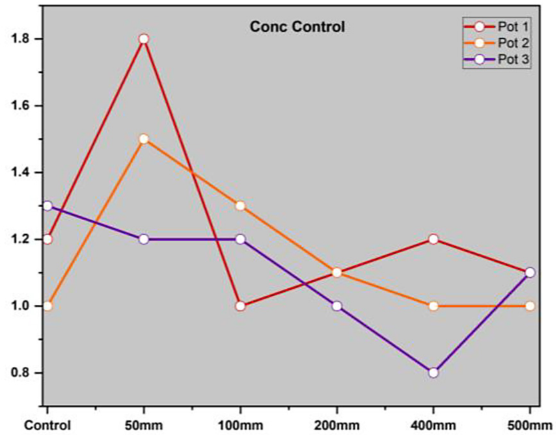

Figure 2. Graphical representation of dry weight

Regularly collected soil samples were tested for electrical conductivity to determine how salt affected soil characteristics. A digital conductivity meter assessed electrical conductivity (EC) to link soil salinity to plant response (Figure 3).

Morphological analysis

Root length, shoot length, and secondary root number were the most important morphological parameters. These measurements were chosen because they indicate how stress affects plant growth and development. At the end of the experiment, the plants were carefully uprooted to protect their root systems. The roots were carefully washed to remove dirt particles. Each root was accurately measured from base to tip using a computerized caliper. Shoot length was measured from stem base to longest leaf tip. Lateral roots from the main root system were manually enumerated as secondary roots. For statistical robustness, all plants in each treatment group had at least five duplicates of each parameter recorded. The mean root length, shoot length, and secondary root number were calculated for further research.

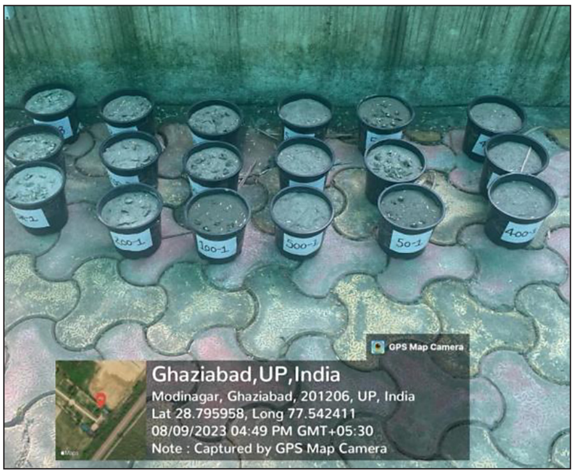

Figure 3. Moth seeds with different salinity

Biochemical analysis

The effect of salt on the interior physiological processes of moth beans was biochemically examined. Quantifying chlorophyll, protein, and enzyme activity was important, since they indicate plant health and stress response.

- chlorophyll content – chlorophyll content was measured using the Arnon method, which extracts pigments in 80% acetone. Fresh leaves from each plant were pulverized into a homogenous mixture in acetone and centrifuged at 10.000 rpm for 10 minutes. After collecting the supernatant, absorbance at 645 and 663 nm was measured with a UV-Vis spectrophotometer. The total chlorophyll content, chlorophyll b, and chlorophyll a were measured in milligrams per gramme of fresh weight using traditional methods.
- protein levels – the Bradford method, which binds Coomassie Brilliant Blue dye to proteins, measured total protein concentration. Leaf samples weighing 0.5 g were homogenized in pH 7.0 phosphate buffer at 12.000 rpm for 15 minutes. The protein content was determined by measuring supernatant absorbance at 595 nm. A calibration curve was made using bovine serum albumin (BSA). Protein was measured in mg/g fresh weight.

Enzyme activity

POD, SOD, and catalase activities in response to stress were measured. To prepare enzyme extracts, 0.5 g of fresh leaf tissue was homogenized in an extraction buffer before centrifugation at 15.000 rpm for 20 minutes. The supernatant was used for enzyme tests. SOD activity was measured by its ability to block NBT photochemical degradation. The reaction mixture included enzyme extract, 50 mM phosphate buffer (pH 7.8), 0.1 mM EDTA, 13 mM methionine, 75 µM NBT, and 2 µM riboflavin. At 560 nm, absorbance was measured, and enzyme activity was provided in units per milligram of protein. At 240 nm, catalase activity was measured by monitoring the breakdown of hydrogen peroxide (H_2O_k). The enzyme extract was combined with 50 mM phosphate buffer (pH 7.0) and 10 mM H_2O_2 in the reaction mixture. Activity was measured in units/mg protein and absorbance decreased. To assess peroxidase activity, guaiacol oxidizing with H_2O_2 was observed. The reaction mixture included phosphate buffer (pH6.0), guaiacol (10 mM), H_2O_2 (10 mM), and enzyme extract. By increasing absorbance at 470 nm, activity was evaluated in units per milligram of protein.

Statistical analysis

All experimental data were statistically evaluated to determine how salinity affects moth bean biochemistry and morphology. To verify data normality, the Shapiro-Wilk test was performed first. One-way ANOVA was utilized to compare treatment groups when the data was normally distributed. Significant pairwise differences were found using Tukey's HSD test for post hoc analysis. When dealing with non-normal data, the Kruskal-Wallis test replaced ANOVA. Correlation analysis was also performed to examine biochemical and morphological relationships at different salinities. A p-value below 0.05 was statistically significant in the SPSS 25.0 analysis. Results for each treatment group were shown as mean +/- SEM. GraphPad Prism (8.0) was used to visualize the data. These graphics showed treatment group trends and differences using bar and line charts. This section describes the methods and materials used to examine the impact of salt on moth beans. This study used controlled growing conditions, a systematic salinity treatment technique, and rigorous morphological and biochemical studies to understand the moth bean response to salt stress. The results are reliable and significant, since rigorous statistical methods were utilized, adding to plant stress physiology knowledge.

DATA ANALYSIS

Morphological data

Morphological data analysis examines how salt affects the root length, shoot length, and secondary root count of moth beans. The plants were given NaCl dosages from 0 to 500 mM before data was obtained. Increasing salinity hindered moth bean growth, evidence showed. As salt levels climbed, moth bean root length fell considerably. With 0 mM (control), roots averaged 15 cm. However, at 500 mM salt, root development stopped and no root length was measured. The bar chart and line graph indicate that salinity gradually shortens roots.

Increased salt decreased shoot and root length similarly. The control group had an average shoot length of 20 cm, which decreased with salinity to 0 cm at 500 mM. As salinity increased, secondary roots decreased from 25 in the control group to 0 at 500 mM. Increased salt restricted root growth and lateral development, as secondary roots were formed to a lesser extent. Significant declines in root, shoot, and secondary root length were seen across different salt levels ($p < 0.05$) utilizing ANOVA analysis of morphological data. The bar graph illustrates that salinity negatively impacts plant development (Fig. 4–6).

Biochemical data

The biochemical study explored how salt affected moth bean enzyme activity, protein levels, and chlorophyll concentration. This section compares these measures between salinity-treated plants and the control group. Primary and secondary sources provided information. As salt increased, chlorophyll decreased. Since their chlorophyll levels were highest, the control group had the best photosynthesis. The trend of chlorophyll degradation was maintained as salinity climbed up from 300 mM. The decline in chlorophyll suggests salinity stress impaired the plant's photosynthetic process, reducing energy generation and stunting growth. As salinity increased, protein content decreased. Protein is necessary for plant development and stress response. Control plants had the most protein, which decreased with salinity. This decrease indicates that salt stress during synthesis and stability affected proteins, which are crucial for numerous metabolic processes. SOD, CAT, and POD activity was tested to assess

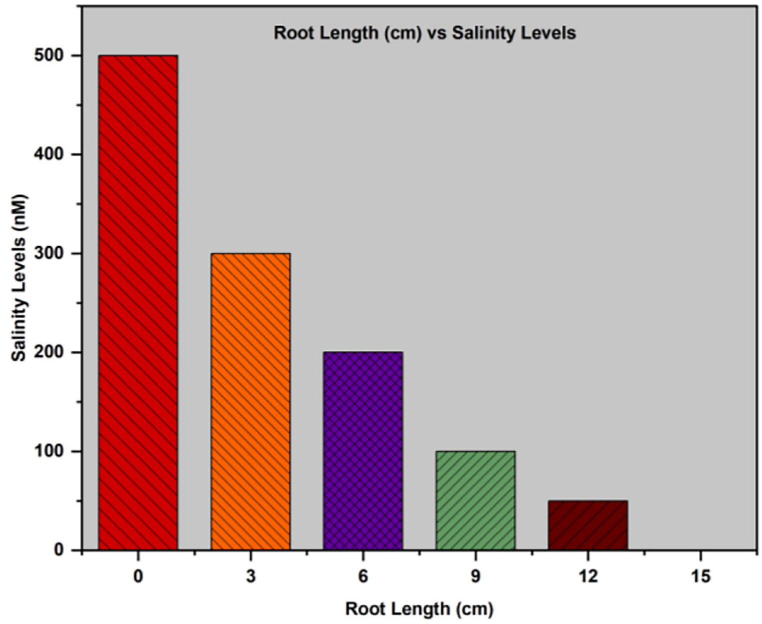

Figure 4. Salinity level (nm) vs root length (cm)

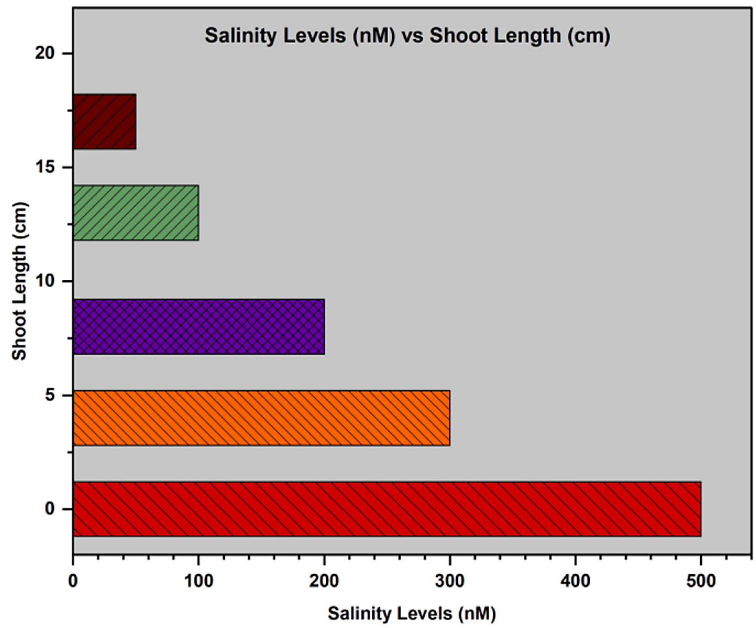

Figure 5. Salinity level (nm)vs shoot length (cm)

the response of moth beans to salt as an oxidative stressor. The findings demonstrated that enzyme activity surged at moderate salinity levels (50 and 100 mM) to resist oxidative damage. Enzyme activity plummeted at 300 and 500 mM salinity, indicating that the plant's antioxidant defenses were overwhelmed. A comparison of control and salinity-treated moth beans showed that salt substantially altered their biochemistry. The stunted growth and altered metabolic profiles indicate physiological stress, supporting the concept that greater salinity causes them. Understanding salt stress and reducing it in crop management is essential for plant health and productivity. Finally, biochemical and morphological data analysis has revealed how salinity affects moth bean development and physiology. The graphical representations show how salinity affects plant development, supporting the necessity to enhance salinity resistance in moth beans.

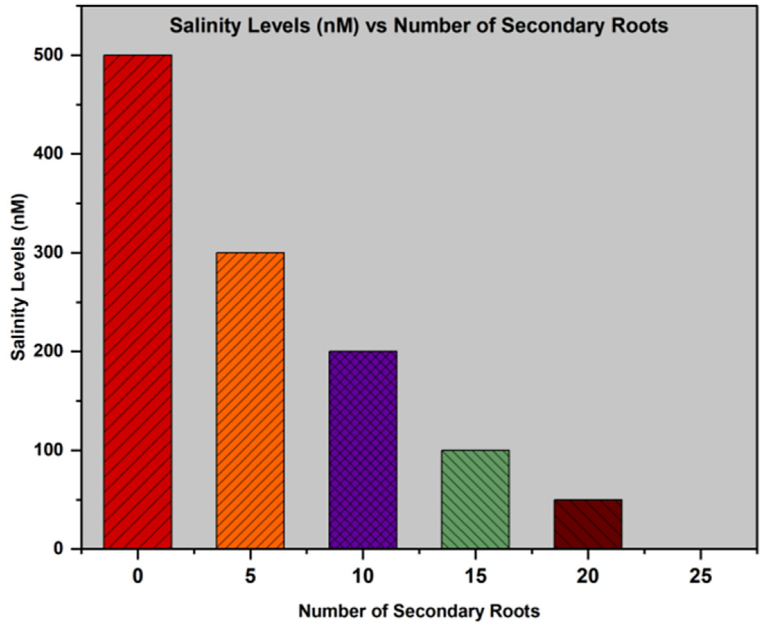

Figure 6. Number of secondary root vs salinity

RESULTS

Morphological findings

Morphological examination showed that salinity levels decreased root and shoot lengths and secondary root numbers. Root length decreased significantly from 0 mM (control) to 500 mM (salinity). Typical control plant roots were 15 cm long. The unusually high salinity stopped root growth at 500 mM, reducing its length to zero centimeters. Similar patterns appeared for shoot length. Averaging 20 cm in length, the control plants' shoot growth decreased with increasing salinity and was non-existent at 500 mM salt. Secondary roots decreased as saline levels rose. Secondary root count peaked at 25 mM in the control group but dropped to zero at 500 mM as salinity rose. These findings show that rising salt levels severely impact moth bean root and shoot growth (Table 3) (Fig. 7–10).

Biochemical findings

The biochemical research revealed how salt stress alters the internal physiological systems of moth bean. Chlorophyll, protein, and enzyme activity studies yielded these results.

Chlorophyll content: Chlorophyll content decreased with increasing salinity. The control plants had the highest chlorophyll content (3.5 mg/g), which reduced to 0.5 mg/g at 500 mM. This reduction in chlorophyll suggests that salinity stress adversely affects the photosynthetic capacity of moth beans.

$$Chlorophy11\ a\left(\frac{mg}{g}\right) = = 12.7 \times A_{663} - 2.69 \times A_{645} \quad (1)$$

$$Chlorphy11\ b\left(\frac{mg}{g}\right) = = 22.9 \times A_{645} - 4.68 \times A_{663} \quad (2)$$

Table 3. Salinity levels vs. root, shoot, and secondary root growth

Salinity (mM)	Root length (cm)	Shoot length (cm)	Number of secondary roots
0	15	20	25
50	12	17	20
100	9	13	15
200	6	8	10
300	3	4	5
500	0	0	0

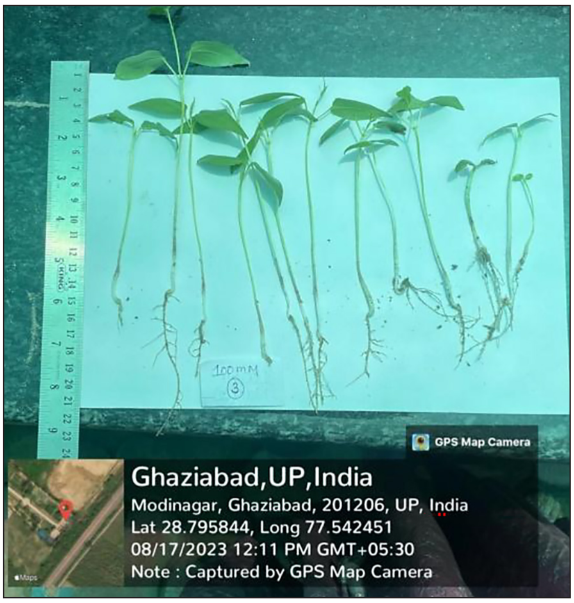

Figure 7. Morphology observed in moth bean with 100 nm salinity

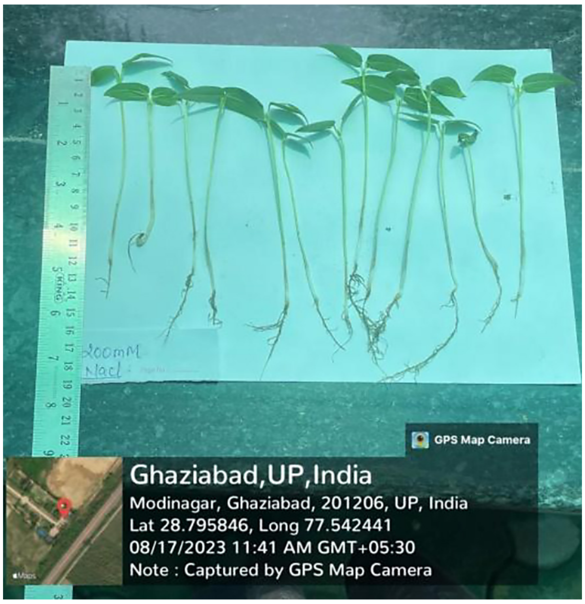

Figure 8. Morphology observed in moth bean with 200 nm salinity

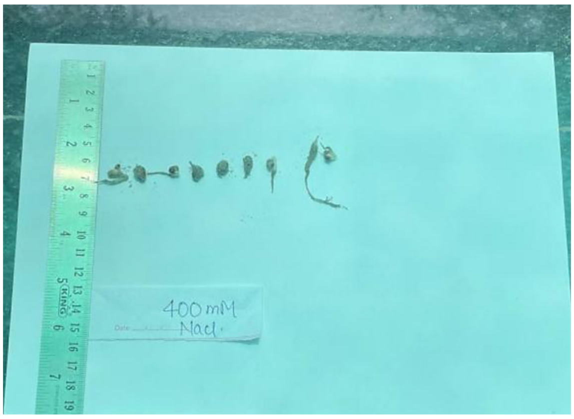

Figure 9. Morphology observed in moth bean with 400 nm salinity

Figure 10. Morphology observed in moth bean with 500 nm salinity

$$Total\ chlorophy\ 11 \left(\frac{mg}{g}\right) = \\ = 20.2 \times A_{645} + 8.02 \times A_{663} \quad (3)$$

where: $A663$ and $A664$ represent the absorbances at wavelengths of 663 nm and 645 nm, respectively.

Protein content: protein levels also showed a downward trend with increasing salinity. The highest protein content (15 mg/g) was observed in the control plants, decreasing to 2 mg/g at 500 mM. This reduction indicates that salinity interferes with protein synthesis and stability, leading to impaired plant growth.

$$Protein\ content \left(\frac{mg}{g}\right) = \\ = \frac{A_{595}}{Standard\ curve\ slope} \quad (4)$$

where: $A595$ is the absorbance measured at 595 nm, and the standard curve slope is obtained from a known protein standard like BSA.

Enzyme activity: the activity of key enzymes involved in oxidative stress response, such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), initially increased at moderate salinity levels (50 mM and 100 mM) but declined sharply at higher salinity levels. The highest enzyme activity was recorded in the control group (50 units/

mg protein), which decreased to 10 units/mg protein at 500 mM. There is a link between biochemical changes and morphological factors that shows how salinity stress affects the bodies and structures of moth beans. The biochemical data back up the morphological results by showing that lower levels of chlorophyll, protein, and enzyme activity caused by salt are closely linked to slower root and shoot growth. Biochemical changes in chlorophyll, protein, and enzyme activity as salinity increases are shown in the bar charts below. Figures 11–13 show how salinity harms moth beans physiologically. Collectively, these data show that salinity is bad for moth beans, because it changes both their physical and chemical composition.

DISCUSSION

This study supports the idea that higher salt levels change the biology of moth beans and slow their growth. As the salt level went up, the length

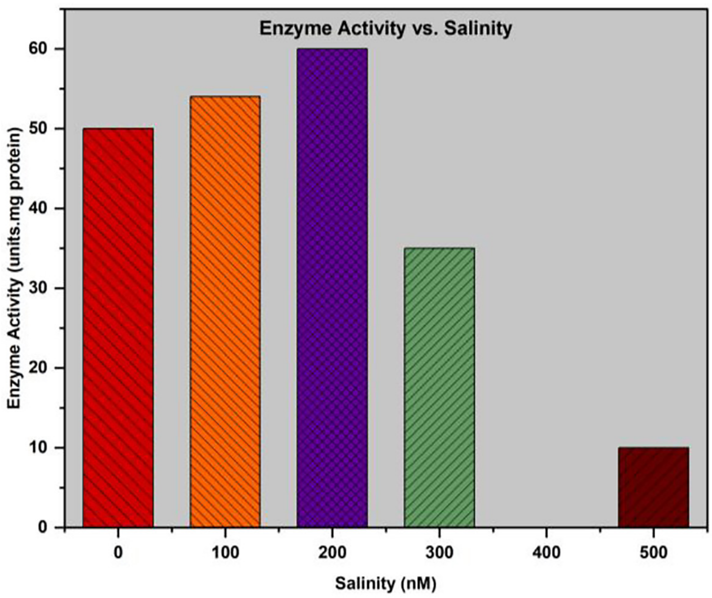

Figure 11. Enzyme activity vs salinity

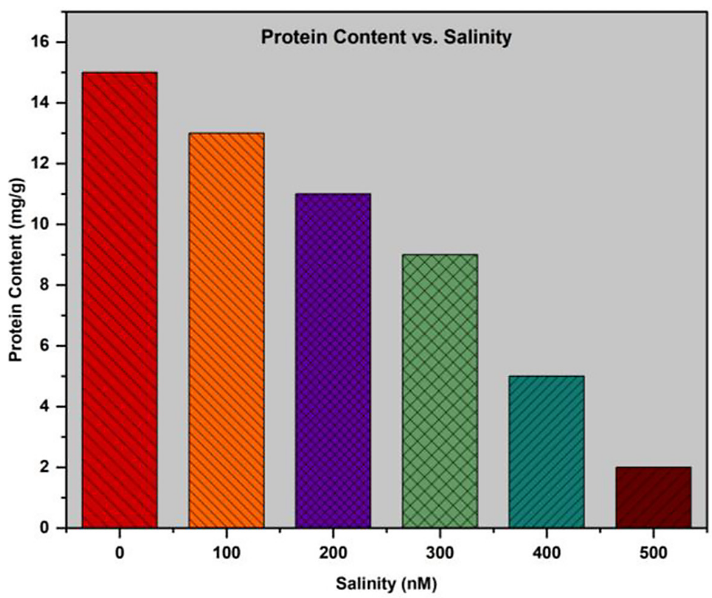

Figure 12. Protein content vs salinity

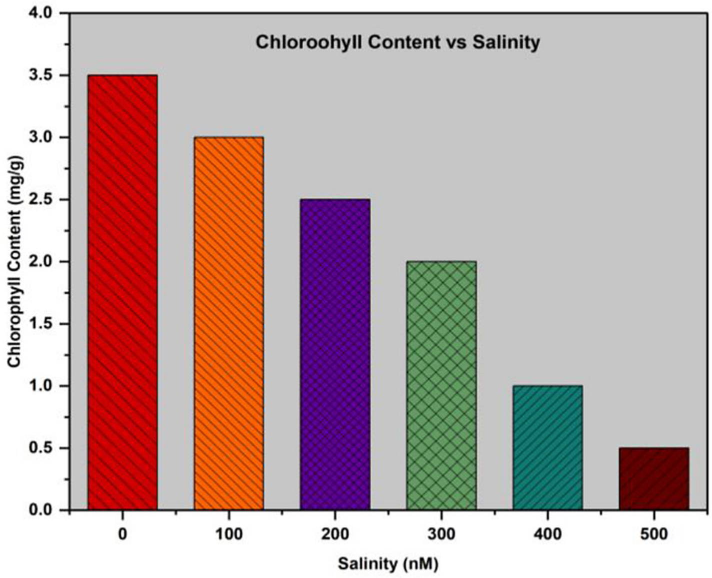

Figure 13. Chlorophyll content vs salinity

of the roots, the length of the shoots, and the number of secondary roots all went down. As expected, salt stress stops root and shoot growth by making it harder for plants to take in water and keep their ions balanced. The biochemical study also showed that the amounts of proteins, enzymes, and chlorophyll decreased as the salt rose. Damage to chlorophyll synthesis and stability occurs as a result of ionic imbalance and osmotic stress caused by salt stress. The deleterious effects of salt on the plant's metabolic activity and protein synthesis machinery may explain the protein reduction (Joshi et al., 2021). Enzyme activity lowers dramatically when salt rises, so the plant cannot survive the oxidative stress caused by salinity, which destroys cells and inhibits growth. Salinity significantly changes the physiological processes of moth beans and hinders their structural development, supporting the idea. Since moth beans are vulnerable to salt stress, agricultural systems must manage salinity to maximize crop development and output.

Comparison with previous studies

This study confirmed prior salinity research on leguminous crops. Research on legumes including beans, peas, and lentils shows that salt inhibits plant growth, lowers chlorophyll, and affects biochemistry. The authors (Saxena et al., 2023) explored how salt affects leguminous plants. When salinity was increased, root and shoot growth, chlorophyll, and protein levels decreased. This study also indicated that antioxidant enzyme activity increased at moderate salt levels and decreased at high salinity. All of these data support the conclusion drawn from the current study that salt stress harms bean biochemistry and morphology.

Salinity stress induces oxidative damage, ionic imbalance, and osmotic stress in leguminous crops, stunting growth and altering physiological processes (Jat et al., 2024). Their study indicated that salinity stress lowered chlorophyll levels in moth beans, supporting the concept that photosynthetic efficiency is hindered. Some study suggests that bean species and even variations can vary substantially in salt tolerance. Some legumes can tolerate salinity better due to their higher antioxidant enzyme activity and osmolyte buildup (Sachdeva et al., 2016). These findings support the hypothesis that salt stress regularly lowers development and affects biochemical composition, but they also suggest that moth bean types and their innate resistance mechanisms may vary. After evaluating legume salt stress literature, the findings from the current study support the hypothesis that salinity is a major abiotic stressor that inhibits moth bean growth and physiology.

Implications for agricultural practices

This study concerned farming operations, especially in semi-arid and dry locations with salt issues. Since moth beans are salt-sensitive, a plan is needed to reduce the salt impact on crop development and productivity. One method is breeding salt-tolerant moth bean cultivars. Breeding efforts that prioritize salt-resistant cultivars could preserve crop yields in salty soils. Salt tolerance genes can be added to moth-resistant bean cultivars through genetic engineering. Managing the land to lower the amount of salt in it is also important (Okon, 2019). There are a number of ways that plants can deal with salt stress. Too much water is used in leaching to remove soluble salts from the root zone. Biochar and compost make the earth better at holding water and lowering the amount of salt that is bad for plants. Managing drainage to lower salinity stress is also very important. If drip irrigation is used, water goes straight to the roots of plants, keeping the soil from becoming too salty. To lower salt stress, plants can be watered with salty or a mix of salts during non-critical growth stages. Lastly, mycorrhizal fungus and rhizobacteria, which help plants grow, make it easier for legumes to handle salt. These good microorganisms are important for healthy agriculture because they help plants take in nutrients, grow roots, and deal with salt stress.

Limitations and future research

The study focused on how salinity impacts moth bean growth and physiology, but it has its downsides. The study was conducted in a controlled environment, which may have overlooked complicated contextual influences in real life. In agricultural situations where temperature, soil heterogeneity, and insect pressure affect salt responsiveness, future study should confirm these findings. Second, the study only tested one moth bean, thus the results may not apply to others. To generate salt-resistant moth bean cultivars, future study should assess salinity tolerance. Third, this study solely assessed enzyme activity, protein levels, and chlorophyll content. Osmolyte build-up, ion transport, and gene expression profiles in salt reactions could be studied.

Secondary data was employed for biochemical analysis, which may induce uncertainty due to experimental circumstances and methods. Primary data on moth bean biochemical reactions to salinity should be collected using established procedures for consistency and reliability. The study examined the impact of salinity on moth beans, but not how it combines with drought or heat. Future research should examine how many agricultural stressors affect moth bean development and physiology. This study found that salt affects moth beans, impacting agriculture and science. Removing restrictions and expanding research can boost moth bean salt stress tolerance and assure crop yield in harsh settings.

CONCLUSIONS

This study showed that greater saline levels impede plant development and physiological activities by affecting moth bean form and biochemistry. As saline levels increased, morphological data showed that root length, shoot length, and secondary root quantity decreased. Salt stress disrupts water intake and ion balance, delaying moth bean growth and structural development. Biochemical analysis demonstrated that salinity decreased chlorophyll, protein, and enzyme activity, as well as morphological changes. less chlorophyll content indicates less photosynthetic capacity, which likely restricted growth. Protein levels drop because salt stress impairs protein synthesis and stability, which are essential for many plant metabolic activities. The decrease in enzyme activity, especially at greater salinity levels, suggests that the oxidative stress caused by salinity overwhelms the plant's antioxidant defenses. These findings support the concept that increased saline levels impede moth bean development structurally and biochemically. Researchers found that moth beans are susceptible to salt stress, so a management plan is needed.

This study has considerable consequences for crop management and breeding, especially in salinity-prone areas. Understanding how saltwater affects moth beans allows for targeted efforts to improve its salinity tolerance. These findings have many applications, but salt-resistant moth beans are particularly intriguing. Breeding strategies can use salinity data on moth bean biochemistry and morphology to select for salt tolerance. Breeding for features like increased chlorophyll, protein, and enzyme activity in saltwater might yield more resilient plants. Genetic engineering can introduce salt tolerance genes from other plants into moth beans to develop resilient transgenic varieties.

The findings from this study can inform breeding and irrigation and soil management measures to minimize agricultural field salt levels. Leaching eliminates surplus salts from the root zone, organic soil additives improve soil structure and water retention, and drip irrigation systems prevent salt accumulation in moth bean harvests. Optimizing watering schedule and method according to plant growth stage can also reduce salt stress at critical phases. Another real-world application of this research is increasing moth bean salinity tolerance with mycorrhizal fungus and PGPR. Beneficial microorganisms improve root development, food intake, and salt-induced oxidative stress defenses. Integrating biological methods with established agronomic procedures can help moth bean farmers manage salinity sustainably. In conclusion, this study lays the framework for breeding, soil management, and biological interventions to boost the salinity tolerance of moth beans. These techniques will make moth bean harvests more salt-resistant, increasing yields and reducing food insecurity in salt-affected areas. This study established the framework for molecular research into moth bean salinity tolerance, which could lead to more precise and cutting-edge crop management.

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