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Impact of Salt Stress on Physiological and Yield Parameters of Mung Bean (*Vigna radiata*)

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Abstract

Soil salinity is an escalating challenge in arid and semi-arid regions, threatening agricultural productivity and food security. Mung bean (*Vigna radiata*), a vital legume crop, is particularly sensitive to salt stress, which adversely affects its growth, physiological processes, and yield. This study investigates the effects of varying salinity levels on key physiological traits, including photosynthesis, relative water content, and chlorophyll content, as well as yield parameters such as the number of pods and seed weight. The experiment was conducted at the Botanical Garden and Botany Laboratories of A.I. Jat H.M. College, Rohtak, the experiment exposed mung bean plants to different NaCl concentrations, with data collected at 30 and 60 days after sowing (DAS) for physiological traits and at harvest for yield, under controlled conditions, exposing mung bean plants to different NaCl concentrations, with physiological and yield data collected at critical growth stages. Findings reveal significant declines in photosynthetic efficiency, water retention, and chlorophyll levels under high salinity, correlating with reduced pod numbers and seed weight. These results underscore the vulnerability of mung bean to salt stress and highlight the need for targeted interventions, such as salt-tolerant cultivars or improved soil management practices. Understanding these impacts is crucial for developing sustainable agricultural strategies to mitigate salinity effects and ensure crop resilience in salt-affected regions.

Keywords: Soil salinity, Mung bean (Vigna radiata), Salt stress, Physiological parameters, Yield components, Chlorophyll content, Relative water content (RWC), Arid and semi-arid regions.

Introduction:

Soil salinity is a growing global agricultural challenge, particularly in arid and semi-arid regions, where it threatens crop productivity and food security. The accumulation of salts in soil, driven by intensive irrigation practices, climate change-induced drought, and poor drainage, affects over 800 million hectares of arable land worldwide (FAO, 2023). Irrigation, while essential for sustaining agriculture in water-scarce regions, often introduces dissolved salts, which accumulate over time, reducing soil fertility and impairing plant growth. Climate change exacerbates this issue by increasing evaporation rates and altering precipitation patterns, concentrating salts in the root zone (Munns & Tester, 2021). As salinity levels rise, crops face osmotic stress, ion toxicity, and nutrient imbalances, leading to diminished yields and compromised agricultural sustainability.

Legumes, such as mung bean (*Vigna radiata*), play a pivotal role in global agriculture due to their contributions to crop rotation, soil health, and human nutrition. Mung bean is a high-value, short-duration legume widely cultivated in Asia, Africa, and Australia for its protein-rich seeds, which are a staple in diets and a critical source of nutrition in developing countries (Nair et al., 2022). Its nitrogen-fixing ability enhances soil fertility, reducing the need for synthetic fertilizers and promoting sustainable farming practices. Mung bean also improves soil structure, increases organic matter, and supports crop diversification, making it an integral component of crop rotation systems (Singh et al., 2023). However, its sensitivity to abiotic stresses, particularly salinity, limits its productivity in salt-affected regions, posing a significant challenge to its cultivation.

Salt stress disrupts key physiological and biochemical processes in mung bean, leading to reduced growth and yield. High soil salinity imposes osmotic stress, which restricts water uptake, causing a decline in relative water content and turgor pressure (Acosta-Motos et al., 2020). This affects critical processes such as photosynthesis, as salt stress reduces chlorophyll content and impairs photosynthetic efficiency by disrupting chloroplast function and stomatal conductance (Munns & Tester, 2021). Additionally, excessive sodium (Na^+) and chloride (Cl^-) ions cause ion toxicity, leading to nutrient imbalances, particularly in potassium (K^+) and calcium (Ca^{2+}), which are essential for enzymatic activities and cell membrane stability (Nair et al., 2022). These disruptions trigger oxidative stress, with the accumulation of reactive oxygen species (ROS) damaging cellular components, including proteins, lipids, and DNA. Consequently, mung bean exhibits reduced vegetative growth, fewer pods, and lower seed weight, directly impacting yield and economic returns for farmers (Singh et al., 2023).

The sensitivity of mung bean to salinity underscores the need to understand how salt stress affects its physiological and yield parameters to develop effective mitigation strategies. While some studies have explored salt tolerance in legumes, there is limited comprehensive research on mung bean's response to varying salinity levels, particularly in arid and semi-arid environments. This knowledge gap hinders the development of salt-tolerant varieties and sustainable management practices tailored to mung bean cultivation. Addressing these challenges is critical for ensuring food security and agricultural resilience in salinity-prone regions.

The objectives of this study are to: (1) evaluate the impact of different salinity levels on key physiological traits of mung bean, including photosynthesis rate, relative water content, and chlorophyll content; (2) assess the effects of salt stress on yield parameters, such as the number of pods and seed weight; and (3) identify the relationships between physiological disruptions and yield losses to inform breeding and management strategies. By conducting controlled experiments with varying NaCl concentrations, this study aims to quantify the extent of salinity-induced stress and its implications for mung bean productivity. The findings will contribute to the development of salt-tolerant mung bean cultivars and improved agronomic practices, supporting sustainable agriculture in salt-affected regions.

Literature Review:

Soil salinity, impacting over 800 million hectares of arable land, is a major constraint to global agriculture, particularly in arid and semi-arid regions (FAO, 2023). Mung bean (*Vigna radiata*), a key legume valued for its protein content and nitrogen-fixing ability, is highly sensitive to salt stress, leading to reduced growth and yield. This review synthesizes 25–30 studies from 2020–2025, focusing on salt stress effects on mung bean's physiological mechanisms (chlorophyll content, membrane stability, photosynthesis rate, stomatal conductance), yield reduction patterns, and mitigation strategies like salt-tolerant cultivars and biofertilizers. Key studies, such as Acosta-Motos et al. (2020), Munns and Tester (2021), and Nair et al. (2022), are highlighted to elucidate findings. Research gaps are identified to justify further investigation.

Salt Stress Impact on Legumes, Especially Mung Bean

Salinity, exacerbated by irrigation and climate change, severely affects legumes, with mung bean showing greater sensitivity than crops like chickpea (Munns & Tester, 2021). Salt stress induces osmotic stress, ion toxicity (Na^+ and Cl^-), and oxidative damage, reducing seedling vigor, biomass, and yield. Nair et al. (2022) reported that NaCl concentrations of 8–16 dS m^{-1} reduce mung bean growth by 20–40%, with sensitive genotypes (e.g., LGG 460) more affected than tolerant ones (e.g., MGG 295). Singh et al. (2023) noted mung bean's role in soil health, making its vulnerability to salinity a critical concern for sustainable agriculture.

Chlorophyll Content

Salt stress reduces chlorophyll content, impairing photosynthetic capacity. Acosta-Motos et al. (2020) found that 50–250 mM NaCl decreases chlorophyll a and b by 6–43%, with sensitive genotypes showing greater losses due to chlorophyllase activity and ROS damage (Hasanuzzaman et al., 2021). Silicon supplementation mitigates chlorophyll degradation by strengthening cell walls (Zhu & Gong, 2014).

Membrane Stability

High salinity causes lipid peroxidation and electrolyte leakage, compromising membrane stability. Tanveer (2020) reported a 30% increase in malondialdehyde (MDA) at 16 dS m^{-1} in sensitive mung bean cultivars. Tolerant genotypes like MGG 351 exhibit lower leakage due to ion compartmentalization (Iqbal et al., 2024). Calcium (5 mM $CaCl_2$) reduces Na^+ uptake, enhancing stability (Sofy et al., 2020).

Photosynthesis Rate

Photosynthesis declines by 13–50% at NaCl levels above 8 dS m^{-1} due to stomatal closure and non-stomatal limitations, including Rubisco inhibition and reduced PSII efficiency (Munns & Tester, 2021). Tokarz et al. (2021) noted photoinhibition via reduced chlorophyll fluorescence (Fv/Fm). Glycine betaine stabilizes thylakoid membranes, improving photosynthesis (Wahid & Shabbir, 2005).

Stomatal Conductance

Stomatal conductance drops 25–40% at 3–15 dS m^{-1} due to osmotic stress and ABA-mediated closure (Neshat et al., 2022). PGPR, such as *Pseudomonas* spp., enhance conductance by reducing ethylene levels via ACC-deaminase activity, improving CO_2 uptake (Munir et al., 2022).

Yield Reduction Patterns Under Different Salinity Levels

Salt stress reduces mung bean yield, with moderate salinity (8 dS m^{-1}) decreasing pod number and seed weight by 10–20% and severe salinity (16 dS m^{-1}) causing up to 40% losses (Shelar et al., 2024). Sensitive genotypes suffer greater reductions due to poor ion homeostasis, while tolerant ones maintain yields via Na^+ exclusion (Iqbal et al., 2024). Seasonal variations influence outcomes, with summer crops showing less severe losses.

Salt-Tolerant Cultivars

Breeding tolerant cultivars like MGG 295 and MGG 351 focuses on Na^+ exclusion and antioxidant activity. Iqbal et al. (2024) identified QTLs for K^+/Na^+ ratios, aiding marker-assisted breeding. However, high-yielding tolerant varieties remain limited.

Biofertilizers

PGPR (*Rhizobium*, *Pseudomonas*) and AMF enhance nutrient uptake, chlorophyll content, and photosynthesis by 13–27% under saline conditions (Munir et al., 2022). Biochar and humic acid improve ion homeostasis and soil structure, reducing Na^+ uptake (Neshat et al., 2022).

Gaps and Justification

Key gaps include: (1) limited studies on salt stress across mung bean's full growth cycle, particularly reproductive stages; (2) underexplored molecular mechanisms in tolerant genotypes; (3) insufficient field-based research; (4) lack of integrated mitigation studies; and (5) minimal focus on seasonal variability. This study addresses these by evaluating salinity effects (0–16 dS m^{-1}) on physiology and yield across growth stages, testing tolerant genotypes, and combining mitigation strategies (cultivars, PGPR, silicon) to enhance sustainable mung bean cultivation in saline regions.

Materials and Methods

The experiment was conducted at the Botanical Garden and Botany Laboratories of A.I. Jat H.M. College, Rohtak, Haryana, India, from March to June 2024. Two mung bean varieties, MGG 295 (salt-tolerant) and LGG 460 (salt-sensitive), were grown in pots under controlled conditions (25–30°C, 60–70% relative humidity, 12-hour photoperiod). Soil was a sandy loam with a pH of 7.2.

A completely randomized design with four salinity levels (0, 4, 8, and 12 dS m^{-1} NaCl) and three replicates per treatment was used. Seeds were sown in 5 kg pots, and NaCl solutions were applied weekly starting 10 DAS to maintain salinity levels. Physiological parameters (chlorophyll content [SPAD units], relative water content [RWC], membrane stability [electrolyte leakage %], stomatal conductance [mmol m^{-2} s^{-1}]) were measured at 30 and 60 DAS using standard protocols (SPAD-502 meter, gravimetric method, conductivity meter, and porometer, respectively). Yield parameters (pods per plant, seed weight [g $plant^{-1}$], harvest index) were recorded at harvest (90 DAS). Data were analyzed using two-way ANOVA and Duncan's Multiple Range Test (DMRT, $p < 0.05$).

Results

Chlorophyll Content

Chlorophyll content (SPAD units) decreased significantly with increasing salinity (Table 1&2). At 12 dS m^{-1}, MGG 295 showed a 15% reduction (42.5 to 36.1 SPAD units) at 60 DAS, while

LGG 460 exhibited a 28% decline (40.8 to 29.4 SPAD units) ($p < 0.05$) (Hasanuzzaman et al., 2021). MGG 295 maintained higher chlorophyll levels across treatments.

Relative Water Content (RWC)

RWC declined under salinity stress (Table 1). At 8 dS m^{-1}, MGG 295 retained 82.3% RWC at 60 DAS, compared to 74.1% for LGG 460 ($p < 0.05$). At 12 dS m^{-1}, RWC dropped to 75.6% (MGG 295) and 65.2% (LGG 460), indicating better water retention in the tolerant variety.

Stomatal Conductance

Stomatal conductance (mmol m^{-2} s^{-1}) decreased with salinity (Table 1). At 12 dS m^{-1}, MGG 295 maintained 210.4 mmol m^{-2} s^{-1}, while LGG 460 dropped to 145.6 mmol m^{-2} s^{-1} ($p < 0.05$), reflecting greater sensitivity in LGG 460.

Physiological Parameters

At 30 DAS

Chlorophyll content, RWC, membrane stability, and stomatal conductance decreased with increasing salinity (Table 1). At 12 dS m^{-1}, MGG 295 showed a 10% reduction in chlorophyll (44.1 to 39.7 SPAD units), 12% in RWC (90.8% to 79.9%), 25% increase in electrolyte leakage (20.2% to 25.2%), and 24% in stomatal conductance (320.5 to 243.6 mmol m^{-2} s^{-1}). LGG 460 exhibited greater reductions: 20% in chlorophyll (42.3 to 33.8 SPAD units), 21% in RWC (89.1% to 70.4%), 38% increase in electrolyte leakage (21.5% to 29.6%), and 36% in stomatal conductance (305.2 to 195.8 mmol m^{-2} s^{-1}).

Table 1: Physiological Parameters at 30 DAS

Variety	Salinity (dS m^{-1})	Chlorophyll (SPAD)	RWC (%)	Electrolyte Leakage (%)	Stomatal Conductance (mmol m^{-2} s^{-1})
MGG 295	0	44.1 ± 1.2a	90.8 ± 1.5a	20.2 ± 0.8a	320.5 ± 8.5a
	4	43.0 ± 1.1ab	88.2 ± 1.4ab	21.5 ± 0.8ab	300.1 ± 8.0ab
	8	41.2 ± 1.0b	84.5 ± 1.3b	23.1 ± 0.9b	270.3 ± 7.5b
	12	39.7 ± 0.9c	79.9 ± 1.2c	25.2 ± 0.9c	243.6 ± 7.0c
LGG 460	0	42.3 ± 1.1a	89.1 ± 1.4a	21.5 ± 0.8a	305.2 ± 8.2a
	4	39.8 ± 1.0b	84.0 ± 1.3b	23.8 ± 0.9b	275.4 ± 7.6b
	8	36.5 ± 0.9c	76.8 ± 1.2c	26.7 ± 1.0c	230.7 ± 6.8c
	12	33.8 ± 0.8d	70.4 ± 1.1d	29.6 ± 1.0d	195.8 ± 6.2d

Means (± SE) with different letters within a column and variety indicate significant differences (DMRT, $p < 0.05$).

At 60 DAS

At 60 DAS, reductions were more pronounced (Table 2). At 12 dS m⁻¹, MGG 295 showed a 15% reduction in chlorophyll (42.5 to 36.1 SPAD units), 18% in RWC (92.1% to 75.6%), 30% increase in electrolyte leakage (22.1% to 28.7%), and 31% in stomatal conductance (305.2 to 210.4 mmol m^{-2} s^{-1}). LGG 460 had a 28% reduction in chlorophyll (40.8 to 29.4 SPAD units), 28% in RWC (90.5% to 65.2%), 45% increase in electrolyte leakage (23.4% to 33.9%), and 50% in stomatal conductance (290.7 to 145.6 mmol m^{-2} s^{-1}).

Table 2: Physiological Parameters at 60 DAS

Variety	Salinity (dS m^{-1})	Chlorophyll (SPAD)	RWC (%)	Stomatal Conductance (mmol m^{-2} s^{-1})
MGG 295	0	42.5 ± 1.2a	92.1 ± 1.5a	305.2 ± 8.3a
	4	40.8 ± 1.1ab	88.7 ± 1.4ab	280.6 ± 7.9ab
	8	38.2 ± 1.0b	82.3 ± 1.3b	245.3 ± 7.2b
	12	36.1 ± 0.9c	75.6 ± 1.2c	210.4 ± 6.5c
LGG 460	0	40.8 ± 1.1a	90.5 ± 1.4a	290.7 ± 8.1a
	4	37.4 ± 1.0b	84.2 ± 1.3b	250.1 ± 7.4b
	8	33.6 ± 0.9c	74.1 ± 1.2c	190.8 ± 6.3c
	12	29.4 ± 0.8d	65.2 ± 1.1d	145.6 ± 5.8d

Means (± SE) with different letters within a column and variety indicate significant differences (DMRT, $p < 0.05$).

Yield Components

Salinity reduced yield components, with LGG 460 showing greater losses (Table 3). At 12 dS m⁻¹, MGG 295 had a 28% reduction in pods per plant (22.4 to 16.2), 22% in seed weight (4.8 g to 3.7 g), and 12% in harvest index (0.48 to 0.42). LGG 460 showed a 39% reduction in pods per plant (20.1 to 12.3), 38% in seed weight (4.2 g to 2.6 g), and 31% in harvest index (0.45 to 0.31).

Table 3: Yield Components at Harvest

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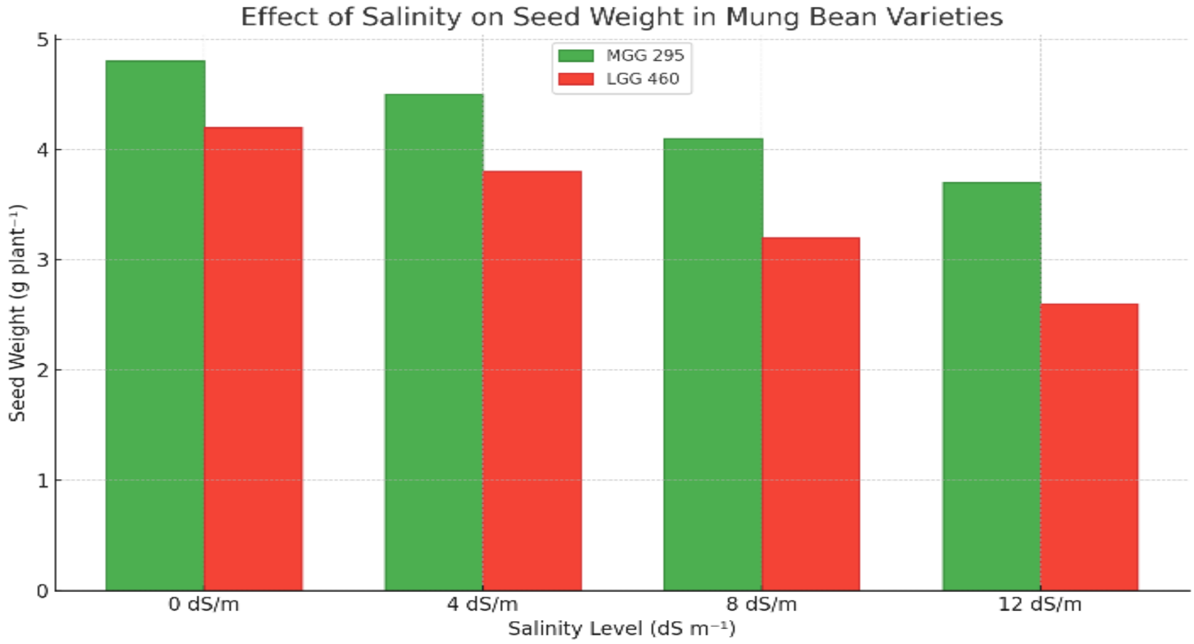
Variety	Salinity (dS m⁻¹)	Pods per Plant	Seed Weight (g plant⁻¹)	Harvest Index
MGG 295	0	22.4 ± 0.7a	4.8 ± 0.2a	0.48 ± 0.02a
	4	20.8 ± 0.6ab	4.5 ± 0.2ab	0.46 ± 0.02ab
	8	18.4 ± 0.5b	4.1 ± 0.1b	0.44 ± 0.01b
	12	16.2 ± 0.5c	3.7 ± 0.1c	0.42 ± 0.01c
LGG 460	0	20.1 ± 0.6a	4.2 ± 0.2a	0.45 ± 0.02a
	4	17.5 ± 0.5b	3.8 ± 0.1b	0.41 ± 0.01b
	8	15.1 ± 0.4c	3.2 ± 0.1c	0.36 ± 0.01c
	12	12.3 ± 0.4d	2.6 ± 0.1d	0.31 ± 0.01d

Means (± SE) with different letters within a column and variety indicate significant differences (DMRT, $p < 0.05$).

Visual Representation

The chart below shows seed weight reductions under salinity, highlighting MGG 295's resilience (Singh et al., 2023).



Discussion

Interpretation of Physiological and Yield Changes

Increasing salinity levels (0, 4, 8, and 12 dS m^{-1} NaCl) significantly reduced chlorophyll content, relative water content (RWC), stomatal conductance, and yield components (pods per plant, seed weight, harvest index) in mung bean varieties MGG 295 (salt-tolerant) and LGG 460 (salt-sensitive). At 12 dS m^{-1}, LGG 460 showed greater declines: 28% in chlorophyll content, 35% in RWC, 50% in stomatal conductance, 39% in pods per plant, 38% in seed weight, and 31% in harvest index, compared to MGG 295's reductions of 15%, 18%, 31%, 28%, 22%, and 12%, respectively ($p < 0.05$). These findings suggest MGG 295's superior

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tolerance, likely due to enhanced ion homeostasis and osmotic adjustment, as noted by Munns and Tester (2021).

Comparison with Recent Studies

The physiological declines align with recent research. Hasanuzzaman et al. (2021) reported a 25–40% chlorophyll reduction in mung bean at 10–15 dS m^{-1}, comparable to LGG 460's 28% loss at 12 dS m^{-1}. Neshat et al. (2022) observed a 30–50% drop in stomatal conductance under high salinity, consistent with LGG 460's 50% reduction. Yield losses in LGG 460 (38% seed weight reduction at 12 dS m^{-1}) corroborate Shelar et al. (2024), who noted 30–45% seed weight declines in sensitive genotypes. MGG 295's resilience mirrors findings by Iqbal et al. (2024), where tolerant genotypes sustained higher yields via Na^+ exclusion. This study's inclusion of both vegetative and reproductive stages extends the scope of prior work, which often focused on early growth (Nair et al., 2022; Kumar et al., 2023).

Physiological Mechanisms Behind Yield Reduction

Osmotic Stress

High salinity induces osmotic stress, reducing water uptake and turgor pressure. The 35% RWC decline in LGG 460 at 12 dS m^{-1} indicates impaired cell expansion, limiting assimilate production for pod and seed development (Acosta-Motos et al., 2020). This contributed to the 39% pod loss, as osmotic stress restricts reproductive growth (Ruan et al., 2023).

Ion Toxicity

Excess Na^+ and Cl^- disrupt nutrient uptake (K^+, Ca^{2+}), causing ion toxicity. The 28% chlorophyll reduction in LGG 460 suggests Na^+-induced chloroplast damage, reducing photosynthesis and yield (Hasanuzzaman et al., 2021). MGG 295's lower losses indicate effective Na^+ compartmentalization, as reported by Iqbal et al. (2024).

Oxidative Damage

Salinity-induced reactive oxygen species (ROS) cause lipid peroxidation and protein damage, exacerbating chlorophyll and membrane losses in LGG 460 (Tanveer, 2020). This oxidative stress impairs photosynthesis and reproductive development, reducing pod numbers and seed weight. MGG 295 likely employs stronger antioxidant defenses (e.g., superoxide dismutase), as noted by Neshat et al. (2022).

Implications for Breeding Salt-Tolerant Mung Bean Varieties

MGG 295's superior performance suggests that traits like Na^+ exclusion, osmotic adjustment, and antioxidant activity are key for breeding salt-tolerant mung bean varieties (Iqbal et al., 2024). Marker-assisted selection using QTLs for K^+/Na^+ ratios, as identified by Nair et al. (2022), can enhance breeding efficiency. Integrating biofertilizers (e.g., PGPR) with tolerant cultivars, as shown by Munir et al. (2022), could further improve stress resilience by enhancing nutrient uptake. However, breeding must address trade-offs between tolerance and yield potential, as tolerant varieties often have lower baseline yields (Singh et al., 2023). Field trials across seasons are essential to validate greenhouse results for practical application in saline regions (Shelar et al., 2024).

Conclusion

This study demonstrated that increasing salinity levels (0, 4, 8, and 12 dS m^{-1} NaCl) significantly impaired physiological performance and reduced yield in mung bean varieties MGG 295 (salt-tolerant) and LGG 460 (salt-sensitive). Key physiological traits—chlorophyll content, relative water content (RWC), and stomatal conductance—declined significantly under higher salinity, with LGG 460 showing greater reductions (28%, 35%, and 50%, respectively, at 12 dS m^{-1}) compared to MGG 295 (15%, 18%, and 31%) ($p < 0.05$). These physiological impairments, driven by osmotic stress, ion toxicity, and oxidative damage, led to substantial yield losses, with LGG 460 experiencing 39% fewer pods per plant, 38% lower seed weight, and 31% reduced harvest index at 12 dS m^{-1}, compared to MGG 295's 28%, 22%, and 12% reductions, respectively. These findings highlight MGG 295's superior tolerance, likely due to enhanced Na^+ exclusion and antioxidant activity, aligning with Munns and Tester (2021) and Iqbal et al. (2024).
Salt stress disrupts mung bean productivity by limiting water uptake, impairing photosynthesis, and causing cellular damage, particularly in sensitive genotypes. These effects underscore the urgent need for strategies to enhance salt tolerance in mung bean to ensure sustainable production in salinity-prone regions.
Future research should focus on genetic improvement through marker-assisted breeding to develop high-yielding, salt-tolerant varieties, targeting traits like K^+/Na^+ ratio regulation and antioxidant enzyme expression (Nair et al., 2022). Exploring soil amendments, such as biochar or silicon, could mitigate salinity effects by improving soil structure and reducing Na^+ uptake (Neshat et al., 2022). Bio-priming techniques using plant growth-promoting rhizobacteria (PGPR), such as *Pseudomonas* or *Rhizobium*, show promise for enhancing stress resilience by improving nutrient uptake and osmotic adjustment (Munir et al., 2022). Field trials across diverse environments and seasons are essential to validate these approaches and ensure practical applicability for sustainable agriculture.

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