

EVALUATING THE IMPACTS OF POTASSIUM CHLORIDE SEED PRIMING AND HYDRO PRIMING ON GERMINATION OF MUNGBEAN (*VIGNA RADIATA L.*) UNDER SALT STRESS

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(Received, 13th December 2025 Accepted 14th July 2026, Published 28th July 2026)

Abstract Seed germination is seriously affected by saline conditions, especially in areas that are arid or semi-arid. The purpose of the present research was to check how seed priming contributes to the enhancement of germination performance even in saline conditions. The present study is a tri-replicated CRD lab experiment in which three priming treatments were used, i.e., unprimed (UP), hydro-priming (HP), and KCl priming (KP; 250 ppm), with three levels of salinity as 0, 25, and 50 mM NaCl. Noted parameters are Germination percentage (GP), Mean germination time (MGT), Coefficient of velocity of germination (CVG), Germination energy (GE), and Germination Rate index. The results demonstrate that as the salinity level rises from 0 mM NaCl to 50 mM, mean germination time increases, while the other parameters like GP, GRI, CVG, and GE decrease in the control due to the high salt concentration. These negative impacts are effectively alleviated by the priming treatments. Among all of the treatments, the KCL priming mitigated saline stress most effectively, even at the highest level of salinity, such as 50 mM NaCl. Although it was less successful than KCl priming, hydro-priming also increased germination as compared to unprimed seeds. Priming enhances stress resistance, as evidenced by the substantial interplay between salinity and priming. All things considered, KCl priming was a successful and useful method for enhancing mungbean germination in saline environments, indicating its possible use for improved crop establishment in salt-affected soils.

[Citation: Ahmed, J., Sherazi, S.H.U.H., Ahmed, H. (2026). Evaluating the impacts of potassium chloride seed priming and hydro priming on germination of mungbean (*Vigna radiata L.*) under salt stress. *J. Life Soc. Sci*, 5: 62. <https://doi.org/10.64013/bbasrjifliss.v2026i1.62>]

Keywords: hydro priming; salinity; osmopriming; germination; mungbean

Introduction

Mung bean (*Vigna radiata L.*) is planted in Pakistan all over the summer season and belongs to the leguminous family (Khan et al., 2005). One of the most important legume crops in Pakistan is the mung bean (*Vigna radiata L.*), which is grown on 6 million hectares across several nations, including China, Bangladesh, South Asia, Southeast Asia, Korea, India, Sri Lanka, Pakistan, Nepal, and the Middle East (Khan et al., 2019). It accounts for around 8.5% of the global pulse area (Khan et al., 2019). Mung bean (100 g) dried seed contains vitamin A (94 mg), iron (7.3 mg), calcium (124 mg), zinc (3 mg), and folate (549 mg) (Savage & Deo, 1989). It is a significant protein source in South and Southeast Asia, where cereals are commonly consumed (Rahmianna et al., 2000). Inadequate crop establishment is frequently mentioned as a significant barrier to its production (Rahmianna et al., 2000). Seed priming is a pre-sowing strategies that is utilized to promote seedling

development with a modification in pre-germination metabolism before radicle protrusion and generally boost the rate of germination, which eventually improves plant yield (Taylor & Harman, 1990). In priming, seeds are dried to their moisture content before soaking, which increases pre-germination metabolic seed activity without causing radicle emergence (McDonald, 2000).

Salinity of the soil greatly lowers agricultural productivity, mostly in semi-arid and dry regions, which make up about 110 million of the 270 million hectares of irrigated land (Smedema & Shitati, 2002). In many crops, the process of seed germination is delayed or even stopped due to salinity (Sedghi et al., 2010). Under low salinity levels, germination is delayed, while if the level of salinity increases, plant germination is not only reduced but can be inhibited eventually (Ghoulam & Fares, 2001). Additionally, salt stress imposes other stress factors such as ion

toxicity on plants, due to unrestricted ion entry in cells in excess of adequate ion concentration and nutrient imbalance, such as witnessed in the exchange of potassium by sodium ion (Sedghi et al., 2010). Salinity thus effects seed germination drastically and prevent the seed to establish effectively. Halopriming, a pre-sowing soaking of seeds in salt solutions that increases germination and seedling emergence in challenging conditions, is one of the most significant advancements (Cantliffe, 1997). The current study aims to investigate how we can mitigate saline stress conditions with seed hydropriming and Osmopriming techniques.

Material and methods

At the Carbon Sequestration and Sustainability Lab, Department of Agronomy, Faculty of Agriculture, University of the Punjab, Lahore, Pakistan (31.49° N, 74.3° E; 220 m elevation), the experiment was conducted to assess the influence of seed priming techniques on germination performance of mungbean (*Vigna radiata* L.) under salinity stress. The experiment was performed using a completely randomized design (CRD) with a factorial arrangement that included two factors: salinity levels (0, 25, and 50 mM NaCl) and seed priming treatments: unprimed seeds (UP), hydro-priming (HP), and KCl priming (KP; 250 ppm). This makes nine treatment combinations, each of which was replicated three times for a total of 27 experimental units. Osmopriming involved soaking seeds in a 250 ppm KCl solution (made by dissolving 250 mg KCl in 1 L distilled water) for 6 hours and then air-drying them at room temperature (20–22°C) to restore their original moisture content. Unprimed seeds (UP) were not treated. For hydro-priming, seeds are soaked in water for 6 hours and then dried to their previous moisture content. In each Petri plate, 10 seeds are used for germination in the lab. To keep the saline stress in Petri plates at 0 mM, 25 mM, and 50mM NaCl solutions are being used and added periodically to maintain stress. A seed was classified as germinated when the radicle protruded about 2 mm, and germination was tracked every day for seven days. Germination-related parameters such as Mean germination time (MGT) were measured (Ellis & Roberts, 1981) equation; $MGT = \Sigma(n * D) / \Sigma D$, n = no of sprouted seeds; D = no of days from initiation of germination. Germination percentage (GP) was estimated by dividing the number of sprouted seeds by the total number of seeds sown and multiplying by 100. Seeds were considered germinated once visible radicles emerged (≥ 2 mm). The final germination percentage was recorded on the seventh day after sowing. Germination Rate Index (GRI) is estimated by protocols of Czabator, (1962), $GRI = GI/DI + G2/D2 + G3/D3 + \dots + Gn/Dn$. Germination energy (GE), with the help of protocols described by International Rules for Seed Testing (ISTA, 2022), was calculated as the percentage of sprouted seeds at the initial count, $GE = (Ng / Nt) * 100$; Ng is number

of seeds that sprouted on the initial count; Nt is the total number of seeds sown. Coefficient Of Velocity Of Germination (CVG) is determined as $CVG = \Sigma N / \Sigma(N * T)$ (Czabator, 1962). N is the number of seeds that sprout each day; T is the number of days since germination initiated. ΣN is the total number of seeds that sprouted; $\Sigma(N * T)$ is the total number of germinated seeds $\times$ matching day. The LSD test (Gomez & Gomez, 1984) was utilized for comparing means when data were statistically assessed using two variables (NaCl dosage and priming treatments).

Results

All measured germination parameters, such as coefficient of velocity of germination (CVG), germination energy (GE), germination percentage (GP), germination rate index (GRI), and mean germination time (MGT), were significantly ($p \leq 0.05$) influenced by salinity stress and seed priming (Table 1). As the concentration of NaCl increased, a gradual decrease in germination ability was noted. Highest germination is showed in the non-saline conditions (0mM), KCl primed seeds have CVG (50.00%), GE (100%), GP (100%) and GRI (6.4167) while these parameters decreased to CVG (25.309%), GE (63.33%), GP (63.33%) and GRI (1.9786) in unprimed seeds as the level of salinity rises to 50mM NaCl. Moreover, delayed germination was indicated by a substantial increase in mean germination time (MGT) with saline stress. Unprimed seeds at 50 mM NaCl had the highest MGT (3.9524 days), while KCl-primed seeds in control conditions had the lowest value (2.000 days).

At all salinity levels, seed priming greatly enhanced germination performance. Unprimed seeds (UP) underperformed at all germination parameters, while KCl priming (KP) and hydropriming (HP) consistently produced better results. Higher CVG, GRI, GE, GP, and together with lower MGT indicated that KCl-primed seeds had improved germination speed and uniformity. Hydropriming was less successful than KCl priming, especially at higher salinity levels, but it did offer a moderate improvement over the control. For every parameter under investigation, the interaction between priming treatments and salinity stress was statistically significant ($p < 0.05$). Even in situations with moderate (25 mM) and high (50 mM) NaCl, KCl priming successfully reduced the negative effects of salinity and maintained comparatively greater germination levels. For example, KCl-primed seeds maintained GE and GP values of 96.67% at 25 mM NaCl, which was much greater than unprimed seeds (80.00%). Similar to hydropriming and unprimed treatments, KCl priming produced better germination properties at 50 mM NaCl. Unprimed seeds, on the other hand, showed the lowest germination indices and the highest MGT under increasing NaCl concentrations, indicating that they were extremely vulnerable to salinity stress.

Table 1. Impact of seed priming and salinity stress on mungbean germination characteristics. According to the LSD test, means denoted by different letters differ significantly at $p < 0.05$

Stress (mM NaCl)	Priming	CVG	GE	GP	GRI	MGT (days)
0	KP	50.000 A	100.00 A	100.00 A	6.4167 A	2.0000 E
0	HP	44.912 AB	93.33 AB	93.33 AB	5.4278 B	2.2407 DE
0	UP	33.018 CD	96.67 AB	96.67 AB	4.6476 C	3.0556 C
25	KP	41.430 B	96.67 AB	96.67 AB	5.4921 B	2.4370 D
25	HP	39.815 B	86.67 BC	86.67 BC	4.5111 C	2.5278 D
25	UP	28.196 DE	80.00 C	80.00 C	2.9508 D	3.5589 AB
50	KP	34.127 C	86.67 BC	86.67 BC	4.1921 C	2.9491 C
50	HP	30.511 CDE	76.67 C	76.67 C	3.1730 D	3.2917 BC
50	UP	25.309 E	63.33 D	63.33 D	1.9786 E	3.9524 A

Discussion

The current study found that salinity stress significantly reduced mungbean germination performance, but seed priming, particularly KCl priming, significantly mitigated these negative effects. These findings are consistent with the well-known susceptibility of seed germination to salt stress, which is regarded as one of the most important limiting variables during early plant establishment. The observed decrease in CVG, GE, GP, and GRI as NaCl levels increased, as well as an increase in MGT, can be attributed to osmotic stress, ion toxicity, and oxidative damage. Salinity decreases the external water potential, decreasing water imbibition, which is required to initiate germination metabolism. Excessive buildup of Na^+ and Cl^- can compromise enzyme activity and membrane integrity, leading to delayed or inhibited germination (Ibrahim, 2016). Furthermore, salinity-induced oxidative stress causes an overproduction of reactive oxygen species (ROS), which harms cellular macromolecules like lipids, proteins, and nucleic acids. As found in the current study, this oxidative imbalance contributes to a lower germination rate and an increase in mean germination time. Similar changes in germination characteristics under salinity have been frequently reported across legumes and cereals, confirming that germination is the most sensitive stage to salt stress (Ibrahim, 2016). Seed priming considerably improved germination characteristics, indicating its use as a pre-sowing approach to increase seed vigour and stress tolerance. Priming initiates pre-germination metabolic activity such as DNA repair, enzyme activation, and mobilization of stored reserves without radicle protrusion. As a result, primed seeds demonstrate faster and more synchronized germination (Ibrahim, 2016). Priming improves physiological aspects such as osmotic correction by building up suitable solutes, stability of the membrane, lowering electrolyte leakage, increasing enzymatic activity, specifically proteases and α -amylase, and antioxidant defense mechanisms, such as catalase (CAT) and superoxide dismutase (SOD). According to recent research, priming also triggers nitric oxide and ROS signalling pathways, which control stress-responsive gene

expression and enhance salt tolerance (Hameed et al., 2025a). KCl priming outperformed hydro-priming and unprimed seeds among the priming treatments. The dual function of potassium (K^+) in plant physiology explains this superiority: ionic balance, as K^+ reduces Na^+ toxicity and preserves cellular ion homeostasis by competing with Na^+ for absorption sites; osmoregulation, in which under saline environments, K^+ helps with osmotic adjustment, which makes it easier to absorb water; and activation of enzymes, as Potassium is a cofactor for many metabolic enzymes. When under stress, these processes work together to improve germination uniformity and speed. Similar results have been documented in which chemical priming agents enhanced metabolic efficiency and ion control during salt stress, improving germination and early growth (Bouzidi et al., 2021). When exposed to stress, primed seeds maintain a physiological imprint that facilitates the quick activation of defense mechanisms such as the activation of the antioxidant system, an increase in mobility of seed reserves, and more expression of stress-tolerant genes.

Recent research showed that the priming treatment ensures embryonic growth by mobilizing protein and carbohydrates in saline conditions (Sghayar et al., 2023). This is the main reason behind the decrease in Mean germination time and increase in Germination rate index values in primed seeds as compared to unprimed ones. Interaction between the salinity and the priming shows that priming gives seeds resistance to survive in the stress conditions in addition to improving and synchronizing germination in the normal conditions. KCl priming showed its potential for resilience by maintaining high germination even at 50mM NaCl. This is due to the early starting of metabolism in the seed, more Na^+/k^+ ratio, increased ion selectivity, an effective antioxidant system, and stabilization of cellular structures. In other crops and wheat, the same trend is seen where the priming enhances germination and seedling establishment in the salinity (Feghhenabi et al., 2020). Hydropiming treatment performed less than the KCl priming but improved the germination in saline conditions as compared to unprimed seeds. It demonstrates that

under saline stress, hydration alone is not enough to mitigate stress; additional chemicals provide physiological benefits such as ionic homeostasis and stress signaling. Osmopriming, on the other hand, offers various ions that help in stress alleviation. Hydropriming only initiates the initial metabolism and increases the water uptake. The outcomes of the KCl priming show the essentiality of combining biochemical regulation with water. These results show how potent and economical seed priming treatment is in increasing crop stand and germination even in saline conditions. Improving germination through priming can greatly increase crop productivity and sustainability, especially in dry and semi-arid places where soil salinization is becoming more common worldwide. Priming is a potential strategy for climate-resilient agriculture, according to recent assessments, particularly in abiotic stress conditions like salinity (Hameed et al., 2025b).

Conclusion

Outcomes of the present experiment unequivocally show that salinity stress negatively impacts mungbean germination performance by decreasing germination rate, uniformity, and percentage while increasing mean germination time. Nevertheless, seed priming greatly reduces these negative impacts, demonstrating its efficacy as a pre-sowing technique for boosting seed vigour in saline environments. By boosting osmotic adjustment, ionic balance, and metabolic activity, KCl priming (250 ppm) significantly improved all germination parameters across a range of salinity levels, making it the most effective of the evaluated treatments. Although hydro-priming had positive impacts as well, it performed less well under increased salinity stress. Priming not only enhances germination under ideal circumstances but also provides resistance under stressful situations, as evidenced by the substantial interaction between priming and salinity. As a result, KCl seed priming might be suggested as an easy, affordable, and scalable method for enhancing mungbean establishment in soils affected by salt. To further strengthen its application in climate-resilient agriculture, future research should concentrate on field validation and investigate the molecular pathways behind priming-induced stress tolerance.

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Statements and Declarations

Data Availability statement

All relevant data are within the manuscript file.

Author's Contribution Statement

JA, and HA collected data and wrote manuscript equally. JA, and SHUHS make final editing. SHUHS supervised the whole research work. All authors have read the final manuscript and approve its submission.

Acknowledgments

Not applicable

Funding

Not applicable

Ethical Statement

Not applicable

Conflict of interest

The investigation was undertaken without any financial conflicts of interest or any other commercial relationships that could be seen as such by any of the authors.



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