Plant Bulletin Vol 4, (2) 2025: 17-26 ISSN: 2959-3379 (Print), 2959-3387 (Online)

Research Article

Evaluation of On-Farm Seed Priming Techniques for Direct-Seeded Rice in Salt-Affected Soils

Syed Saqlain Hussain[1], Muhammad Qaisar Nawaz[2], Khalil Ahmed[2], Muhammad Irfan[3], Ghulam Qadir[2], Muhammad Sarfraz[2], Muhammad Rizwan[2], Muhammad Faisal Nawaz[2], Muhammad Shakar[2], Ghulam Shabbir[2], Amar Iqbal Saqib[2]

[1]Sugarcane Research Institute Faisalabad, Pakistan
[2]Soil Salinity Research Institute Pindi Bhattian, Pakistan
[3]Pulse Research Station Sialkot, Pakistan
Correspondence: khalilahmeduaf@gmail.com

ABSTRACT

The study was conducted to assess how soil moisture levels (dry vs. moist) combined with various seed-priming methods influence the growth and yield of direct-seeded rice grown in salt-affected soils. The experiment was carried out in a moderately saline field with pHs 8.68, ECe 4.30 dS m^{-1} and SAR 34.40 $(mmol\ L^{-1})^{1/2}$, using a split-plot design with three replications. NIAB-IRRI-9 served as the test variety. The treatments consisted of two soil conditions—dry and moist (at field capacity)—and seven seed-priming methods: untreated dry seed; soaking in canal water for 24 hours; soaking in tube-well water for 24 hours; soaking in 2% $CaSO_4$ for 24 hours; soaking in 2% K_2SO_4 for 24 hours; sprouted seed; and chitted seed. Among all treatments, $CaSO_4$ priming gave the most favorable results, enhancing plant height, tiller production, 1000-grain weight, and overall paddy yield. The benefits of priming were particularly noticeable under dry soil conditions.

Keywords: Adaptations. Climate Change. Cropping Pattern. Seasonal Variations. Water Table. seed priming; direct seeded rice; $CaSO_4$; salt stress, soil conditions

INTRODUCTION

Rice (*Oryza sativa* L.), is staple food of more than 50% world's population which is globally cultivated on area of 167 million hectares (FAO, 2018). The common practice of rice cultivation is transplanting of rice seedlings into the puddled soil. However, this practice is expensive, time consuming, laborious and led to over-exploitation of fresh water resources (Khush, 2015). Therefore, this traditional practice of rice cultivation is dwindling due to limited fresh water resources, labor cost and uneven distribution of rain fall and scientist are focusing on water saving dry direct seeded rice. Research studies revealed that direct seeded rice improves the crop stand (Ishfaq *et al.*, 2018), save labor and water by 50% (Ranbir *et al.*, 2019) and provides higher economic returns (Bhullar *et al.*, 2018).

Article History

Received: October 11, 2024, Accepted: August 20, 2025, Published: September 06, 2025.

Direct seeded rice technology may be adopted by (I) sowing the rice in un-puddled soils maintained at field capacity (two to four weeks after seeding locally known as vatter) (II) sowing in dry soil followed by irrigation (Ishfaq *et al.*, 2018; Devkota *et al.*, 2020). However, weed infestations, poor germination and non-uniform crop stands are major constraints in the wide-scale adoption of direct seeded rice (Saha *et al.*, 2021). The rapid and early emergence of the seedlings, efficient root system and suppressing weeds are desirable traits for attaining full yield potential in direct seeded rice (Sandhu *et al.*, 2019). Soil moisture is a very critical factor for seedling emergence in direct seeded rice (Alam *et al.*, 2020). Soil moist condition is an innovative approach tht conserve the soil moisture and reduces the risk of seedling mortality (Dhillon *et al.*, 2021). Furthermore, direct seeded rice requires a sustainable and effective approach that facilitate rapid and uniform seedlings emergence and vigorous growth.

Seed priming is a very practical mature, and facile technique for vigorous and uniform crop establishment in direct seeded rice (Marthandan *et al.*, 2020; Farooq *et al.*, 2011). Seed priming involves soaking of seeds in water (hydropriming) or different salt solutions (halopriming) that trigger the pre-germination metabolic processes without allowing emergence (Farooq *et al.*, 2019). Improved seed invigoration for rapid and uniform crop stand through seed priming was successfully employed for dry seeded rice in drought stress areas (Du *et al.*, 2002), seedling vigor for weed competitiveness (Anwar *et al.*, 2013) and yield stability under aerobic conditions (Rehman *et al.*, 2011). In rice, primed seeds usually demonstrated early growth, efficient root system, greater germination uniformity, higher grain and dry matter yield and decreased the need for high seeding rates (Du *et al.*, 2019; Ali *et al.*, 2020). Therefore, seed priming is a short-term effective technique for increasing seedling vigor and better crop establishment under different stresses in different crops including rice (Dhillon *et al.*, 2021). Rapid, higher, uniformed and synchronized germination of primed seeds occurs due to increased total sugar contents, enhanced amylase activity (Arif *et al.*, 2019), enzyme activation (Lee & Kim. 2000) and metabolic repair (Farooq *et al.*, 2006). Rehman *et al.* (2015) studied the effect of water malmanagement strategies (direct seeded rice at field capacity and direct seeded rice in alternate wetting and drying) and different priming techniques (hydro priming, 3.3% moringa leaf extracts, 2.2% $CaCl_2$ and 2.2% KCl). They concluded that crop performance was much better in the term of seedling emergence, productive tillers, grain yields, water productivity and benefit cost ratio with application of moringa leaf extracts and $CaCl_2$ for alternate wetting and drying irrigation. Similarly, (Dhillon *et al.*, 2021) conducted a field trial to study the positive effects of different priming agents (control, water, KNO_3 @ 2.0%, GA3@50 ppm and polyethylene glycol (-0.6 MPa)) on growth and grain yield of direct seeded rice established by two methods sowing in moist conditions and sowing in dry soil. Results revealed that seed priming with KNO_3 @ 2.0%, GA_3@50 ppm increased the grain yield of direct seeded rice by 7-11% which can be attributed to rapid germination, better root growth, seedling vigor, reduced spikelet sterility and improvement in yield characteristics. They concluded that KNO_3, GA_3 has good potential for seed invigoration and crop establishment under the different stress conditions. Lee *et al.* (1998) suggested that priming is very effective approach for better crop establishment under abiotic stress condition that may reduce 0.9-3.7 days from planting to 50% germination. Farooq *et al.* (2006) reported that seeding priming with $CaCl_2$ resulted significantly higher emergence rates in rice under salinity and chilling stress. Zheng *et al.* (2002) also found significantly higher antioxidant activities in primed seed under salinity stress. Similarly seed priming with KNO_3 resulted better seedling establishment of sunflower under salinity and drought stress (Kaya *et al.*, 2006). Very limited work has been done regarding the seed priming techniques in direct seeded rice under field conditions. Therefore, this work was planned to evaluate the impact of different seed priming techniques on growth and yield improvement of direct seeded rice in salt affected soils established by two different methods.

MATERIALS AND METHODS

Experimental Site

The study was executed from 2016 to 2018 at research farm of Soil Salinity Research Institute, Pindi Bhattian Pakistan (altitude 184 m, latitude 31.8950° N and longitude 73.2706° E) with the objective to introduce different seed priming techniques for yield improvement of direct seeded rice under saline sodic soils. The average weather conditions were: minimum temperature (21.3 ± 2.5°C), maximum temperature (41.5 ± 2.8°C), minimum relative humidity (21.6 ± 3.8%), maximum relative humidity (74.6 ± 2.7%), maximum sunshine hours, 14 h and 10 min and minimum sunshine hours, 11 h and 11 min.

Experimental design and treatment details

A saline sodic field (pH of soil saturated paste (pH_s)= 8.60, Electrical conductivity of soil extract (EC_e) = 4.30 dSm^{-1} and Sodium absorption ratio (SAR) =34.40) was selected, leveled and well prepared for sowing according to the treatment plan. The experiment was laid out in split plot design with three replications keeping sub plot size 4m x 6m. Treatments included in the study were: A. Soil conditions (sowing in moist conditions & sowing in dry conditions) and B. Seed priming techniques (T_1. dry seed without soaking, T_2. Canal water soaking for 24 hrs, T_3. Seed soaked in tube well water for 24 hrs, T_4. Seed soaked in $CaSO_4$ solution (2%) for 24 hrs, T_5. Seed soaked in $CaCl_2$ solution (2%) for 24 hrs, T_6. Sprouted seed (seed soaked in water for 24 hrs and then put under gunny bag till sprouting) and T_7. Chitted seed (Chitting is a method of preparing paddy/rice seed before planting. The seed is moistened with water and then dumped/wrapped in the water-soaked jute bag and placed in the shade but shielded from direct sunlight. After two to three days, the seed will sprout, and whitish radical part will appear, called chitted seed). Soil conditions were kept in main plots whereas seed priming techniques were placed in subplots. Fertilizers at the rates of N 110, P 90, and K 60 kg ha^{-1} in the form of urea, single superphosphate and sulphate of potash were used. During 1st week of June seed of rice variety NIAB-IRRI-9 @ 50 kg ha^{-1} was broadcasted in their respective plots and ridges were made at 60 cm apart. All the agronomical practices and plant protection measures were carried out uniformly.

Data Collection and Statistical Analysis

The crop was harvested at physical maturity, and data were recorded for plant height, number of tillers per m², panicle length, number of grains per panicle, 1000-grain weight, and grain yield. Before performing analysis of variance (ANOVA), the Shapiro-Wilk test was applied to assess the normality of the data. The results indicated that the data were normally distributed ($P \leq 0.05$), justifying the use of ANOVA for further analysis. The data were then subjected to ANOVA following Steel et al. (1997), and the least significant difference (LSD) among treatment means was calculated at the 5% probability level using the STATISTIX 8.1 software package.

RESULTS

Plant Height (cm)

Pooled data of three years revealed that plant height plant height was significantly affected by seed priming techniques, soil conditions and their interactions (Table 1). Mean value data showed that seed primed with $CaSO_4$ solution 2% for 24 hrs produced maximum plant height of 101.25 cm followed by chitted seed and both treatments were significant ($P < 0.05$) from each other. On contrary, minimum plant height of 84.45 cm was recorded where dry seeds (non-primed) were used for direct seeding of rice. Data regarding soil conditions also depicted significant effect on plant height, maximum plant height (95.41 cm) was divulged where seeds were sown in dry soil conditions and it was statistically significant ($P \leq 0.05$) from sowing in moist conditions. Interaction among seed priming techniques and soil conditions showed that maximum plant height (103.60 cm) was measured where seed was primed with $CaSO_4$ solution 2% for 24 hrs and seed was sown in dry soil condition followed by the treatment where chitted seed was used under the same soil condition (99.90 cm). At the same time, minimum plant height was measured with dry (non-primed) seed under both dry and moist soil conditions.

Table 1. Effect of different seed priming techniques under different soil conditions (dry & moist) on plant height (cm)

Seed priming techniques	**Dry sowing**	**Moist sowing**	**Mean**
Dry seed	85.40 e	83.50 e	84.45 D
Tube well water soaking for 24 hrs	94.50 cd	91.80 d	93.15 C
Canal water soaking for 24 hrs	95.00 c	93.60 cd	94.30 C
Seed primed with $CaSO_4$ solution (2%) for 24 hrs	103.60 a	98.90 b	101.25 A
Seed primed with K_2SO_4 solution (2%) for 24 hrs	94.67 cd	91.80 d	93.24 C
Sprouted seed	94.80 cd	93.50 cd	94.15 C
Chitted seed	99.90 b	94.93 c	97.42 B
Mean	95.41 A	92.58 B	

LSD for seed priming techniques=2.1870 LSD for soil conditions=1.2109 LSD for interaction=3.0930

Number of Tillers m^{-2} Data in (Table 2) showed that soil conditions, seed priming techniques and their interaction also significantly influenced the number of tillers of direct seeded rice. With respect to soil conditions maximum number of tillers (279.76) were recorded where seed was sown in dry soil condition and it was statistically ($P < 0.05$) higher than number of tillers (246.71) observed in moist condition. Number of tillers were also positively influenced by the seed priming techniques with maximum tillers of 310.17 in treatment of $CaSO_4$ solution (2%) for 24 hrs, however, it was non-significant from chitted seed. Minimum number of tillers (202) were recorded in control (non-primed). Data about interaction depicted that seed primed with $CaSO_4$ solution (2%) for 24 hrs and sown in dry soil conditions produced maximum number of tillers (339.33) statistically higher than all other treatments. On the other hand, minimum tillers (181.67) were observed where un-primed seeds were sown in moist conditions.

Table 2. Effect of different seed priming techniques under different soil conditions (dry & moist) on number of tillers m^{-2}

Seed priming techniques	Dry sowing	Moist sowing	Mean
Dry seed	222.33 g	181.67 h	202.00 E
Tube well water soaking for 24 hrs	256.00 e	218.33 g	237.17 D
Canal water soaking for 24 hrs	266.67 e	241.00 f	253.84 C
Seed primed with $CaSO_4$ solution (2%) for 24 hrs	339.33 a	281.00 c	310.17 A
Seed primed with K_2SO_4 solution (2%) for 24 hrs	280.33 cd	262.33 e	271.33 B
Sprouted seed	268.00 de	262.33 e	265.17 BC
Chitted seed	325.67 b	280.33 cd	303.00 A
Mean	279.76 A	246.71 B	

LSD for seed priming techniques=14.8350 LSD for soil conditions=11.889 LSD for interaction=6.8378

Number of Grains Panicle^{-1}

Concerning to number of grains panicle^{-1} a significant effect was found for soil conditions (Table 3). Dry sowing of direct seeded produced maximum number of grains panicle^{-1} (143.14) significantly ($P < 0.05$) higher than moist sowing. While among seed priming techniques, maximum grains panicle^{-1} (149.50) were divulged by $CaSO_4$ solution (2%) for 24 hrs, however, it was at par with chitted seed. Interactive effect revealed that sowing the seeds in dry soil conditions and priming with $CaSO_4$ solution (2%) for 24 hrs produced the highest number of grains panicle^{-1} (156), however, it was non-significant from chitted seed and seed primed with K_2SO_4 solution (2%) for 24 hrs and sown in dry soil conditions.

Table 3. Effect of different seed priming techniques under different soil conditions (dry & moist) on number of grains panicle^{-1}

Seed priming techniques	Dry sowing	Moist sowing	Mean
Dry seed	134.00 d	117.00 e	125.50 D
Tube well water soaking for 24 hrs	138.00 cd	134.00 d	136.00 C
Canal water soaking for 24 hrs	140.00 bcd	135.00 cd	137.50 C
Seed primed with $CaSO_4$ solution (2%) for 24 hrs	156.00 a	143.00 bcd	149.50 A
Seed primed with K_2SO_4 solution (2%) for 24 hrs	147.00 abc	136.00 cd	141.50 BC
Sprouted seed	136.00 cd	132.00 d	134.00 C
Chitted seed	151.00 ab	140.00 bcd	145.50 AB

Mean	143.14 A	133.86B	

LSD for seed priming techniques= 7.8419 LSD for soil conditions=8.1853 LSD for interaction=11.0900

Panicle Length (cm)

Panicle length data depicted in (Table 4) also showed significant difference for soil conditions and seed priming techniques. Dry sowing was more effective than moist sowing and produced panicle length of 23.44 cm, statistically ($P < 0.05$) higher than moist sowing. Among priming techniques, treatment with $CaSO_4$ solution (2%) for 24 hrs divulged maximum panicle length (25.30 cm), however, statistically it was non-significant ($P < 0.05$) from chitted seed and sprouted seed. At the same time minimum panicle length (19.45 cm) was recorded by unprimed seed. Interactive effect between soil conditions and priming techniques showed that seed primed with $CaSO_4$ solution (2%) for 24 hrs was at par with chitted seed sown in both dry and moist soil conditions.

Table 4. Effect of different seed priming techniques under different soil conditions (dry & moist) on panicle length (cm)

Seed priming techniques	**Dry sowing**	**Moist sowing**	**Mean**
Dry seed	20.80 ef	18.10 f	19.45 D
Tube well water soaking for 24 hrs	22.90 bcde	22.00 de	22.45 BC
Canal water soaking for 24 hrs	21.20 e	20.60 ef	20.90 CD
Seed primed with $CaSO_4$ solution (2%) for 24 hrs	26.20 a	24.40 abcd	25.30 A
Seed primed with K_2SO_4 solution (2%) for 24 hrs	25.60 ab	22.83 cde	24.21 AB
Sprouted seed	22.63 cde	21.80 de	22.21 BC
Chitted seed	24.80 abc	24.30 abcd	24.55 A
Mean	23.44 A	22.00 B	

LSD for seed priming techniques= 2.0632 LSD for soil conditions= 0.2839 LSD for interaction=2.9179

1000 -Grain Weight (g)

As far as 1000-grain weight is concerned, data in (Table 5) displayed a significant of soil conditions on 1000-grain weight. The maximum 1000-grain weight (21.38 g) was observed where seed was sown in dry conditions statistically higher than moist conditions. Among seed priming techniques maximum 1000-grain weight (21.49 g) was recorded where seed priming was done with $CaSO_4$ solution (2%) for 24 hrs which was statistically ($P < 0.05$) alike with chitted seed and seed primed with K_2SO_4 solution (2%) for 24 hrs. Interaction among priming techniques and soil conditions did not show significant effect on 1000-grain weight.

Table 5. Effect of different seed priming techniques under different soil conditions (dry & moist) on 1000 grain weight (g)

Seed priming techniques	**Dry sowing**	**Moist sowing**	**Mean**
Dry seed	21.00 cd	20.95 d	20.97 E
Tube well water soaking for 24 hrs	21.35 ab	21.00 cd	21.17 D
Canal water soaking for 24 hrs	21.39 ab	21.19 ab	21.29 CD
Seed primed with $CaSO_4$ solution (2%) for 24 hrs	21.53 a	21.45 ab	21.49 A

Seed primed with K_2SO_4 solution (2%) for 24 hrs	21.45 ab	21.33 ab	21.39 AB
Sprouted seed	21.47 ab	21.23 bc	21.35 BC
Chitted seed	21.49 a	21.40 ab	21.44 AB
Mean	21.38 A	21.25 B	

LSD for seed priming techniques= 0.1271 LSD for soil conditions=0.1125 LSD for interaction=0.2446

Paddy yield (t ha^{-1})

Pooled data (Table 6) showed a significant effect of seed priming techniques, soil conditions, and their interaction on the paddy yield of direct-seeded rice. Among the priming treatments, seeds primed with $CaSO_4$ solution (2%) for 24 hours produced the highest paddy yield of 4.35 t ha^{-1}, followed by chitted seeds and seeds primed with K_2SO_4 solution (2%) for 24 hours; however, all treatments were statistically similar ($P < 0.05$). In contrast, the minimum paddy yield (3.73 t ha^{-1}) was recorded in the control treatment where unprimed seeds were directly sown. Soil conditions also had a significant effect, with dry sowing producing a statistically higher paddy yield (4.16 t ha^{-1}) than moist sowing ($P < 0.05$). The interactive effect revealed that seeds primed with $CaSO_4$ solution (2%) for 24 hours and sown under dry soil conditions produced the maximum paddy yield of 4.45 t ha^{-1}, although this value was statistically similar ($P < 0.05$) to chitted seeds and seeds primed with K_2SO_4 solution (2%) under the same soil conditions. The lowest paddy yield (3.66 t ha^{-1}) was obtained from unprimed seeds sown under moist conditions.

Table 6. Effect of different seed priming techniques under different soil conditions (dry & moist) on paddy yield (t ha^{-1})

Seed priming techniques	**Dry sowing**	**Moist sowing**	**Mean**
Dry seed	3.80 fg	3.66 g	3.73 D
Tube well water soaking for 24 hrs	4.03 cdef	3.89 efg	3.96 C
Canal water soaking for 24 hrs	4.11 bcde	3.92 efg	4.01 BC
Seed primed with $CaSO_4$ solution (2%) for 24 hrs	4.45 a	4.25 abc	4.35 A
Seed primed with K_2SO_4 solution (2%) for 24 hrs	4.35 ab	4.01 cdef	4.18 AB
Sprouted seed	4.00 def	3.96 def	3.98 C
Chitted seed	4.43 a	4.15 bcd	4.29 A
Mean	4.16 A	3.97 B	

LSD for seed priming techniques= 0.2576 LSD for soil conditions= 0.0712 LSD for interaction=2.9179

DISCUSSION

Poor and uneven seedling establishment and higher risk of weeds invasion are major constrains in wide-scale adoption of direct seeded rice (Kumar *et al.,* 2011). Several seed priming strategies like nutrient priming, osmorpiming, hormonal-priming and hydropriming are used in rice crop to induce tolerance against wide range of abiotic stresses in the field (Paparella *et al.,* 2015). These pre-sowing seed invigoration treatments enables seed to tolerate environmental stresses and improved seed germination and vigor by activation of cellular defense responses and increasing enzymatic activities (Jisha *et al.,* 2013). Therefore, in current study, different seed priming treatments were evaluated in two different soil conditions (dry and moist conditions) in a salt-affected field and results revealed that seed priming techniques and soil conditions significantly influenced the agronomical characters and yield performance of direct seeded rice. Beneficial effects of osmorpiming under stress conditions on germination, seedling emergence, early growth and grain yield have been reported by different researchers (Pame *et al.,* 2015; Zheng *et al.,* 2016; Watanabe *et al.,* 2018) which strengthen the findings of current study. Dhillon *et al.* (2021) and Marthandan *et al.* (2020) reported that under stressful environment, osmopring enhanced the tolerance of crop by improving the osmotic regulation, increasing the activities of antioxidant enzymes (peroxidase, super oxide dismutase and catalase) and establishing the well-developed root system. Priming treatments modifies the physiological processes in seed (stimulates elongation of mesocotyl and coleoptile) and thereby enables the emerging seedling to withstands adverse conditions (Dunand *et al.,* 2020; Sukifto *et al.*, 2020).

Among all the tested treatments, seed priming with $CaSO_4$ and sowing in dry conditions improved the performance of direct seeded rice in the term of plant height, number of tillers, 1000-grain weight and paddy yield. Improved growth and yield performance of direct seeded rice under salinity stress conditions by hydropriming and halopriming could be explained by improved activities of antioxidant scavenger enzymes like catalase (CAT), superoxide dismutase (SOD) and α- amylase leading to increase in cell division and carbohydrate mobilization and decrease in lipid peroxidation (Zheng *et al.*, 2016; Arif *et al.*, 2019; Du *et al.,* 2019). Previously, Hussain *et al.* (2015) also stated the better seedling growth of primed rice as compared to non-primed due to enhanced starch metabolism. Moreover, improved performance of rice crop in dry soil conditions as compared to moist conditions may be explained by that osmopriming imposed stress imprints due to reduced availability of water to seeds under dry soil conditions leading to higher root density (Pame *et al.*, 2015). This deep and well-developed root system uptake nutrient and water more efficiently leading to more number of tillers, grain panicle^{-1}, reduced the spikelet sterility and higher paddy yield (Dhillon *et al.,* 2021). Sowing methods significantly influenced the growth characteristics and final grain yield of rice crop (Fuki, 2002). Similarly, Ruan *et al.* (2002) also opined that primed seed performed better and have higher vigor level than non-primed seed under low moisture soil conditions. Improved plant height, number of tillers and grain panicle^{-1} with osmo primnig under soil conditions may be ascribed by better nutrition, improved assimilatory and root system thus making the emerging seedling adaptive to low moisture soil conditions in direct seeded rice (Rehman *et al.,* 2015). Higher number of tillers and grain panicle^{-1} by priming with $CaSO_4$ in dry soil conditions are in agreement with findings of (Rehman *et al.,* 2015) in which seed priming of direct seeded rice with moringa leaf extract or $CaCl_2$ in alternate wetting and drying soil conditions improved the crop stand, encourages early tillering because alternate wetting and drying soil conditions reduced the growth of unproductive tillers and improves light penetration to canopy (Yang, & Zhang, 2010).

Better performance of seed primed with $CaSO_4$ under salt stress conditions was perhaps due to positive effects of Ca on membrane (Shannon & Francois, 1977) increased rate of cell division (Bose & Mishra, 1999) increased contents of soluble sugars, increased α-amylase activity and enhanced oxygen uptake (Afzal *et al.,* 2008) reduced uptake of toxic nutrients (Na) and higher uptake of beneficial nutrients (K) (Shannon & Francois, 1977). Similarly, Afzal *et al.* (2008) reported that among different osmo-priming treatments $CaSO_4$ was most effective priming agents to increased germination, fresh and dry weight of root and increased the uptake of K^+ in wheat under salinity stress. Priming the seed with Ca compound especially $CaSO_4$ reduced mortality% of groundnut seedling under adverse soil conditions and improved the overall plant growth in the term of leaf development and dry mass production (Murata *et al.,* 2008).

CONCLUSION

The results of the present study demonstrated that seed priming improved the performance of direct-seeded rice in salt-affected fields. Among the treatments, seed priming with $CaSO_4$ proved to be more effective in counteracting the detrimental effects of salt stress and enhanced crop performance in terms of plant height, number of tillers, 1000-grain weight, and paddy yield. Furthermore, the advantages of seed priming were more pronounced under dry soil conditions.

REFERENCES

Afzal, I., Rauf, S., Basra, S. M. A., & Murtaza, G. (2008). Halopriming improves vigor, metabolism of reserves and ionic contents in wheat seedlings under salt stress. Plant, Soil and Environment, 54(9), 382-388. https://doi.org/10.17221/408-PSE

Alam, K., Bell, R. W., Hasanuzzaman, M., Salahin, N., Rashid, M., Akter, N., Akhter, S., Islam, M. S., Islam, S., & Naznin, S. (2020). Rice (*Oryza sativa* L.) establishment techniques and their implications for soil properties, global warming potential mitigation and crop yields. Agronomy, 10(6), 888. https://doi.org/10.3390/agronomy10060888

Ali, L. G., Nulit, R., Ibrahim, M. H., & Yien, C. Y. S. (2020). Enhancement of germination and early seedling growth of rice (Oryza sativa) var. FARO44 by seed priming under normal and drought stressed conditions. Journal of Plant Nutrition, 43(11), 1579-1593. https://doi.org/10.1080/01904167.2020.1739297

Anwar, M. P., Juraimi, A. S., Mohamed, M. T. M., Uddin, M. K., Samedani, B., Puteh, A., & Man, A. (2013). Integration of agronomic practices with herbicides for sustainable weed management in aerobic rice. The Scientific World Journal, 2013, 1-12. 10.1155/2013/916408

Arif, T. U., Afrin, S., Polash, M. A. S., Akter, T., Ray, S. R., Hossain, T., & Hossain, M. A. (2019). Role of exogenous signaling molecules in alleviating salt-induced oxidative stress in rice (*Oryza sativa* L.): A comparative study. Acta Physiologiae Plantarum, 41(5), 69. 10.1007/s11738-019-2861-6

Bhullar, M. S., Singh, S., Kumar, S., & Gill, G. (2018). Agronomic and economic impacts of direct seeded rice in Punjab. Agricultural Research Journal, 55(2), 236-242. DOI:10.5958/2395-146X.2018.00038.8.

Bose, B., & Mishra, T. (1999). Influence of pre-sowing soaking treatment in Brassica juncea seeds with Mg-salts on growth, nitrate reductase activity, total protein content and yield responses. Physiology and Molecular Biology of Plants, 5(1), 83-88.

Devkota, K. P., Yadav, S., Khanda, C., Beebout, S. J., Mohapatra, B. K., Singleton, G. R., & Puskur, R. (2020). Assessing alternative crop establishment methods with a sustainability lens in rice production systems of Eastern India. Journal of Cleaner Production, 244, 118835. https://doi.org/10.1016/j.jclepro.2019.118835

Dhillon, B. S., Virender, K., Pardeep, S., Navjyot, K., Gurjit, S. M., & Sudhanshu, S. (2021). Seed priming with potassium nitrate and gibberellic acid enhances the performance of dry direct seeded rice (*Oryza sativa* L.) in North-Western India. Agronomy, 11(5), 849. https://doi.org/10.3390/agronomy11050849

Du, B., Luo, H., He, L., Zhang, L., Liu, Y., Mo, Z., Pan, S., Tian, H., Duan, M., & Tang, X. (2019). Rice seed priming with sodium selenate: Effects on germination, seedling growth, and biochemical attributes. Scientific Reports, 9(1), 1-9. 10.1038/s41598-019-40849-3

Du, L. V., & Tuong, T. P. (2002). Enhancing the performance of dry seeded rice: Effects of seed priming, seedling rate, and time of seedling. In S. Pandey, M. Mortimer, L. Wade, T. P. Tuong, K. Lopez, & B. Hardy (Eds.), Direct Seeding: Research Strategies and Opportunities (pp. 241-256). International Rice Research Institute.

Dunand, R. T. (2020). Gibberellic acid seed treatment in rice. LSU Agricultural Experiment Station Reports. Retrieved November 25, 2020, from http://digitalcommons.lsu.edu/agexp/510

Farooq, M., Basra, S. M. A., Tabassum, R., & Afzal, I. (2006). Enhancing the performance of direct seeded fine rice by seed priming. Plant Production Science, 9(4), 446-456. https://doi.org/10.1626/pps.9.446

Farooq, M., Siddique, K. H. M., Rehman, H. U., Aziz, T., Lee, D. J., & Wahid, A. (2011). Rice direct seeding: Experiences, challenges and opportunities. Soil and Tillage Research, 111(2), 87-98. https://doi.org/10.1016/j.still.2010.10.008

Farooq, M., Usman, M., Nadeem, F., Rehman, H. U., Wahid, A., Basra, S. M. A., & Siddique, K. H. M. (2019). Seed priming in field crops: Potential benefits, adoption and challenges. Crop and Pasture Science, 70(9), 731-771. https://doi.org/10.1071/CP18604

Food and Agriculture Organization (FAO). (2018). FAOSTAT database. Rome. Retrieved March 12, 2018, from http://www.fao.org/faostat/en/#data/QC/

Fuki, S. (2002). Rice cultivar requirement for direct-seeding in rainfed lowlands. In S. Pandey, M. Mortimer, L. Wade, T. P. Tuong, K. Lopez, & B. Hardy (Eds.), Direct seeding: Research strategies and opportunities (pp. 15-39). International Rice Research Institute.

Hussain, S., Zheng, M., Khan, F., Khaliq, A., Fahad, S., & Peng, S. (2015). Benefits of rice seed priming are offset permanently by prolonged storage and the storage conditions. Scientific Reports, 5, 8101. https://doi.org/10.1038/srep08101

Ishfaq, M., Akbar, N., Khan, I., Anjum, S. A., Zulfiqar, U., Ahmad, U. M., Ahmad, M., & Chattha, M. U. (2018). Optimizing row spacing for direct seeded aerobic rice under dry and moist fields. Pakistan Journal of Agricultural Research, 31(4), 291-299. https://doi.org/10.17582/journal.pjar/2018/31.4.291.299

Jisha, K. C., Vijayakumari, K., & Puthur, J. T. (2013). Seed priming for abiotic stress tolerance: An overview. Acta Physiologiae Plantarum, 35(5), 1381-1396. https://doi.org/10.1007/s11738-012-1186-5

Kaya, M. D., Okçu, G., Atak, M., Çıkılı, Y., & Kolsarıcı, Ö. (2006). Seed treatments to overcome salt and drought stress during germination in sunflower (*Helianthus annuus* L.). European Journal of Agronomy, 24(4), 291-295. 10.1016/j.eja.2005.08.001.

Khush, G. S. (2015). Punjab's water woes and India's food security. Journal of Crop Improvement, 29(1), 1-5. 10.1080/15427528.2015.997655.

Kumar, V., & Ladha, J. K. (2011). Direct seeding of rice: Recent developments and future research needs. Advances in Agronomy, 111, 297-413. https://doi.org/10.1016/B978-0-12-387689-8.00001-1

Lee, S. S., & Kim, J. H. (2000). Total sugars, α-amylase activity, and emergence after priming of normal and aged rice seeds. Korean Journal of Crop Science, 45(2), 108-111.

Lee, S. S., Kim, J. H., Hong, S. B., & Yun, S. H. (1998). Effect of humidification and hardening treatment on seed germination of rice. Korean Journal of Crop Science, 43(3), 157-160.

Marthandan, V., Geetha, R., Kumutha, K., Renganathan, V. G., Karthikeyan, A., & Ramalingam, J. (2020). Seed priming: A feasible strategy to enhance drought tolerance in crop plants. International Journal of Molecular Sciences, 21(3), 8258. 10.3390/ijms21218258

Murata, M. R., Zharare, G. E., & Hammes, P. S. (2008). Pelleting or priming seed with calcium improves groundnut seedling survival in acid soils. Journal of Plant Nutrition, 31(10), 1736-1745. 10.1080/01904160802324787

Pame, A. R., Kreye, C., Johnson, D., Heuer, S., & Becker, M. (2015). Effects of genotype, seed P concentration and seed priming on seedling vigor of rice. Experimental Agriculture, 51(3), 370-381. 10.1017/S0014479714000362

Paparella, S., Araújo, S. S., Rossi, G., Wijayasinghe, M., Carbonera, D., & Balestrazzi, A. (2015). Seed priming: State of the art and new perspectives. Plant Cell Reports, 34(8), 1281-1293. 10.1007/s00299-015-1784-y.

Ranbir, S., Tripathi, R. S., Sharma, D. K., Chaudhari, S. K., Joshi, P. K., Dey, P., Sharma, S. K., Sharma, D. P., & Gurbachan, S. (2019). Effect of direct seeded rice on yield, water productivity and saving of farm energy in reclaimed sodic soil. Indian Journal of Soil Conservation, 47(3), 230-235.

Rehman, H. U., Basra, S. M. A., & Farooq, M. (2011). Field appraisal of seed priming to improve the growth, yield and quality of direct seeded rice. Turkish Journal of Agriculture and Forestry, 35(4), 357-365. DOI. 10.3906/tar-1004-954

Rehman, H. U., Kamran, M., Basra, S. M. A., Afzal, I., & Farooq, M. (2015). Influence of seed priming on performance and water productivity of direct seeded rice in alternating wetting and drying. Rice Science, 22(4), 189-196. https://doi.org/10.1016/j.rsci.2015.03.001

Ruan, S., Xue, Q., & Tylkowska, K. (2002). The influence of priming on germination of rice (Oryza sativa L.) seeds and seedling emergence and performance in flooded soil. Seed Science and Technology, 30(1), 61-67.

Saha, S., Munda, S., Singh, S., Kumar, V., Jangde, H., Mahapatra, A., & Chauhan, B. (2021). Crop establishment and weed control options for sustaining dry direct seeded rice production in Eastern India. Agronomy, 11(2), 389. https://doi.org/10.3390/agronomy11020389

Sandhu, N., Yadaw, R. B., Chaudhary, B., Prasai, H., Iftekharuddaula, K., Venkateshwarlu, C., Annamalai, A., Xangsayasane, P., Battan, K. R., & Ram, M. (2019). Evaluating the performance of rice genotypes for improving yield and adaptability under direct seeded aerobic cultivation conditions. Frontiers in Plant Science, 10, 159. https://doi.org/10.3389/fpls.2019.00159

Shannon, M. C., & Francois, L. E. (1977). Influence of seed pretreatments on salt tolerance of cotton during germination. Agronomy Journal, 69(4), 619-622. 10.2134/agronj1977.00021962006900040024x

Steel, R. G. D., Torrie, J. H., & Dickey, D. A. (1997). Principles and procedures of statistics: A biometrical approach (3rd ed.). McGraw-Hill.

Sukifto, R., Nulit, R., Kong, Y. C., Sidek, N., Mahadi, S. N., Mustafa, N., & Razak, R. A. (2020). Enhancing germination and early seedling growth of Malaysian indica rice (*Oryza sativa* L.) using hormonal priming with gibberellic acid (GA3). AIMS Agriculture and Food, 5(4), 649-665. https://doi.org/10.3934/agrfood.2020.4.649

Watanabe, K., Oda-Yamamizo, C., Sage-Ono, K., Ohmiya, A., & Ono, M. (2018). Alteration of flower colour in Ipomoea nil through CRISPR/Cas9-mediated mutagenesis of carotenoid cleavage dioxygenase 4. Transgenic Research, 27(1), 25-38. 10.1007/s11248-017-0051-0

Yang, J. C., & Zhang, J. H. (2010). Crop management techniques to enhance harvest index in rice. Journal of Experimental Botany, 61(12), 3177-3189. https://doi.org/10.1093/jxb/erq112

Zheng, H. C., Jin, H. U., Zhi, Z., Ruan, S. L., & Song, W. J. (2002). Effect of seed priming with mixed-salt solution on germination and physiological characteristics of seedling in rice (*Oryza sativa* L.) under stress conditions. Journal of Zhejiang University (Agriculture & Life Sciences), 28(2), 175-178.

Zheng, M., Tao, Y., Hussain, S., Jiang, Q., Peng, S., Huang, J., Cui, K., & Nie, L. (2016). Seed priming in dry direct-seeded rice: Consequences for emergence, seedling growth and associated metabolic events under drought stress. Plant Growth Regulation, 78(2), 167-178. https://doi.org/10.1007/s10725-015-0083-5