Original Research Article

**Effect of foliar applied signal molecules on growth and yield traits for Rice (*Oryza sativa.* L) resilience under salinity stress**

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ABSTRACT

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| **Aims:** To study the effect of foliar applied signal molecules on growth, yield & yield attributes parameters of rice (*Oryza sativa.* L) under salinity stress.  **Study design:** Randomized block design  **Place and Duration of Study:** Agricultural College Farm, Bapatla, Andhra Pradesh during *kharif*, 2023-24  **Methodology:** Experiment was carried out with two contrast varieties (MCM103- Salt tolerant, as a check; BPT 5204- Salt susceptible) and with eight treatments *viz.,* MCM 103 (Check variety) - T1, 0.25 mM/L of SNP - T2, 0.50 mM/L of SA -T3, 0.50 mM/L of BR -T4, 0.25 mM/L SNP+ 0.50 mM/L SA -T5, 0.25 mM/L SNP+ 0.50 mM/L BR -T6, 0.25 mM/L SNP+ 0.50 mM/L SA+ 0.50 mM/L BR -T7 and No spray control -T8 in three replications.  **Results:** The present study revealed that the foliar application of consortia, 0.25mM/L Sodium nitro prusside + 0.50mM/L Salicylic acid + 0.50mM/L Brassinosteroids (T7) showed better results under salinity stress of 4 dSm-1 in terms of improving growth besides increasing the yield and yield contributing characters in BPT 5204, a salt sensitive variety of rice.  **Conclusion:** The foliar application of 0.25 mM/L of Sodium nitro prusside + 0.50 mM/L of Salicylic acid + 0.50 mM/L of Brassinosteroids at before and after reproductive stages under soil salinity of 4 dSm-1 can be recommended, where salinity is the major problem to minimize the effect of salinity stress in BPT 5204 after validation through on-farm trials. |

*Keywords: grain quality, salinity stress, signal molecules, spikelet fertility %, yield*

1. INTRODUCTION

Rice (*Oryza sativa* L*.*) is the most vital cereal food crop, serving as a staple for nearly half of the global population. It ranks as the second most crucial food grain after wheat, with approximately three billion people relying on it for 50 to 80 percent of their daily caloric intake (Ma *et al. 2*007). In the year 2023/2024 worldwide production of rice accounts for 513.54 million metric tons and India stands second in global rice production that accounts for 137 million metric tons, which is 26% of total rice production (USDA 2024). China stands first in rice consumption with 150 million metric tons, followed by India where 118 million metric tons of rice consumed in 2023/2024 (Statista 2024).

Rice is cultivated under various climate and soil-water conditions, but environmental stressors significantly threaten its yield, necessitating increased production to satisfy the demands of a growing population. Biotic and abiotic stresses, including heat, salinity, drought, and cold, severely impact rice growth and yield, posing substantial threats to global food security (Mantri *et al. 2*012). Amid these stress factors, salinity is a significant factor, particularly following drought, because rice is highly susceptible to salt. Soil salinity, characterized by excessive salt accumulation, adversely affects crop development. Two primary contributors of increased salinization of agricultural areas are rising mean sea level and inefficient irrigation practices (Negacz *et al.* 2022). Globally, over 833 million hectares of soils are currently affected by high salinity (FAO 2021), with India seeing 6.73 mha of irrigated land degraded by salt (Sharma *et al.* 2004). Approximately, greater than 10 percent of the agricultural cropland is impacted by salinity, presenting a severe risk to global food security.

Rice crop can tolerate salinity levels around 3 dSm-1, beyond that, significant yield losses occur (Gao *et al.* 2007). The seedling and early vegetative stages  (Lutts *et al.* [1995](https://thericejournal.springeropen.com/articles/10.1186/s12284-019-0317-7" \l "ref-CR24" \o )), and the reproductive (booting) stage  (Singh *et al.* [2009](https://thericejournal.springeropen.com/articles/10.1186/s12284-019-0317-7" \l "ref-CR39" \o "Singh RK, Redoña E, Refuerzo L (2009) Varietal improvement for abiotic stress tolerance in crop plants: special reference to salinity in rice. In: Abiotic stress adaptation in plants. Springer, Dordrecht, pp 387–415)) are the critical stages under salinity stress. The reduction of endogenous phytohormones correlates with salinity's detrimental effects on growth and germination (Debez *et al. 2*001) and are vital for alleviating salt stress and fostering adaptive mechanisms (Harris *et al*. 2002). Plant Growth Regulators (PGRs) perform as signalling agents (Pal *et al. 2*018) that enhance resilience to salt stress through physiological and developmental changes.

Brassinosteroids, derived from sterols, regulate various physiological, developmental, and biochemical functions, such as seed germination and stress adaptation. Their application under salt stress enhances antioxidant enzyme activity and modifies ion content, ultimately improving yield (Hayat *et al. 2*010). Sodium Nitroprusside (SNP), a Nitric Oxide (NO) donor, improves plant resilience to abiotic stresses, optimizing Na+/K+ ratios and enhancing antioxidant activity (Ali *et al. 2*017). Salicylic Acid (SA), a key regulator, helps plants cope with stress by optimizing ion transport, maintaining redox homeostasis, and reducing oxidative damage through increased enzyme activity and osmoprotectant synthesis (Dolatabadian *et al. 2*009). At this juncture, the exogenous application of signalling molecules may be the promising strategy for enhancing rice productivity in saline-prone areas.

2. material and methods

**2.1 Experimental site and soil**

A field experiment was carried out in *kharif* during 2023-24 at Agricultural College Farm, Bapatla, Andhra Pradesh. It is geographically located at 15°54′ Northern latitude, and 80°25′ Eastern longitude, with an altitude of 5.49 m above the mean sea level (MSL), which is about 8 km away from the Bay of Bengal in the Krishna Agro- Climatic Zone of Andhra Pradesh. In this investigation, two distinct varieties with varying salt tolerance were chosen. The first type, BPT 5204 is sensitive to salt, while the second type, MCM 103 exhibits higher tolerance to salt stress which is used as a check to compare the impact of signal molecules which were foliar applied on BPT 5204. The present study was conducted in randomized block design with eight treatments *viz*., MCM 103 (Check variety) - T1, 0.25 mM/L of SNP - T2, 0.50 mM/L of SA -T3, 0.50 mM/L of BR -T4, 0.25 mM/L SNP+ 0.50 mM/L SA -T5, 0.25 mM/L SNP+ 0.50 mM/L BR -T6, 0.25 mM/L SNP+ 0.50 mM/L SA+ 0.50 mM/L BR -T7 and No spray control -T8 in three replications with the salinity level 4 dSm-1. The foliar application of different signal molecules was done at two different growth stages (before and after reproductive stages). The data were collected for various parameters associated with growth related to salinity tolerance at four different stages: Maximum tillering, Panicle initiation, Anthesis and Physiological maturity stage. Data on the yield and yield attributes were recorded at harvest and the quality parameters were recorded after the harvest.

**2.2 Observations recorded**

Five plants were randomly tagged in every plot for recording data at different stages of growth period. Plant height and number of tillers per plant were recorded as growth parameters at four different stages *viz.,* Maximum tillering, Panicle initiation, Anthesis and Physiological maturity stages in five randomly tagged plants. Days to 50% flowering was recorded when the plants attained 50% flowering in each replication and in each treatment was expressed in days.

Yield and yield components were recorded from the five tagged plants used for recording morphological characters. The panicles harvested from the tagged plants were threshed, cleaned and total number of grains per panicle were counted and recorded. From that, number of filled and unfilled grains were counted and Spikelet fertility was worked out using the following formula and expressed in percent. Straw yield also recorded and harvest index was calculated.

(Number of filled spikelets /Total number of spikelets) × 100

In order to quantify the head rice and broken kernel as quality parameters, the polished kernels are passed through a rice grader. Then the whole grains from the broken grains were separated. If the grains retained full or 3/4th of the size were considered as head rice and those grains were weighed for calculating the head rice recovery (%).

Head Rice Recovery (%)

Broken kernel (%) was calculated by using the following formula

Broken (%)

**2.3 Statistical Analysis**

The data were analyzed statistically following analysis of variance (ANOVA) technique suggested by Panse and Sukhathme (1978) for randomized block design (RBD). The statistical hypothesis of equalities of treatment mean was tested by F- test in ANOVA at 5 per cent level of significance. Critical difference was correlated at 5 per cent level of significance to compare different treatment means.

3. results and discussion

**3.1 Plant Height**

Generally, an increased soil salinity levels can stress plants, impeding their growth. This might be due to excess salt disrupts root water uptake, causes dehydration, limits nutrient absorption, induces toxicity, and causes physiological drought that results in stunted growth. Shalhevet *et al.* (1995) stated that the salinity tends to have a greater impact on shoot growth than on root growth. In the present study, salinity stress reduced the plant height and the reduction was more in salt susceptible variety (BPT 5204) than that of salt tolerant variety (MCM 103) at all the four stages, showed in table 1 and figure 1. The results of our present study coincide with the studies of Islam *et al.* (2007) and Kibria *et al.* (2017) who witnessed that the increased salinity resulted in the reduction of plant height significantly in all the rice varieties. In addition, Hasamuzzaman *et al.* (2009); Dramalis *et al.* (2021) and Bhowmik *et al.* (2021) reported that in comparison to the susceptible variety, the tolerant variety exhibited a higher plant height. In this study, after the foliar spray of signal molecules, the plant height was improved significantly in all foliar treated plants. Among different foliar application treatments, foliar spray of consortia (T7) recorded the highest plant height of 85.09, 89.71 and 90.08 cm and it was 10.1, 10.1 and 7.6 % higher than that of control (T8), followed by T6, T5 and also on par with salt tolerant MCM 103 (maximum plant height by 10.6, 12.8 and 9.9 % over control -T1) at panicle initiation, anthesis and physiological maturity stages respectively. The above results were supported by the studies of Hussain *et al. 2*023 in rice, Escobar *et al*. (2010) in maize and Pai & Sharma (2023) who stated that the exogenous application of brassinosteroids, sodium nitro prusside, as nitric oxide (NO) donor and salicylic acid had a positive significant effect on plant height under salinity stress. Brassinosteroids can interact with endogenous auxin synergistically, results in cell elongation and cell proliferation of meristematic tissue (Sairam 1994).

**3.2 Number of Tillers per plant**

Numerous reports (Zeng *et al.,* 2000; Haq *et al.,* 2009 and Hasanmuzzaman *et al*., 2009) have been indicated that salinity negatively influences tillering in rice, as this factor plays a crucial role in determining the formation of grain-bearing panicles that are directly correlated to yield and higher reduction of tillering capacity was observed in salt sensitive variety compared to tolerant variety in rice. In this present study, an increased number of tillers per plant was recorded in the salinity tolerant variety (MCM 103) compared to the salinity sensitive variety (BPT 5204) in saline stress environment. The present study revealed that the application of plant growth regulators as signal molecules, increased tillering capacity significantly under salinity stress compared to control and were shown in table 1 and figure 1. Among different foliar application treatments of signal molecules, foliar spray of consortia (T7) recorded higher of number of tillers per plant of 13.33, 13.67 and 14.00 and increased by 38.3, 35.7 and 28.1 % over the control (T8) and also on par with salt tolerant, MCM 103 variety (T1), which recorded maximum number of tillers by 57.0, 55.6 and 46.4 % over the control at panicle initiation, anthesis and physiological maturity stages, respectively. These results are supported by Habib *et al*. (2016), Hussain *et al*.(2023) and Okasha (2018) who reported that exogenously applied sodium nitroprusside (SNP), Brassinosteroid and Salicylic acid, respectively on rice led to significant increase in number of tillers under salinity stress.

**3.3 Spikelet fertility percentage**

The present study is in accordance with Xu *et al.* (2024) and Li *et al.* (2023) who reported that the salinity stress reduced the number of filled grains and spikelet fertility % in the salt sensitive variety more than that of the salt tolerant variety. This reduction in the number of filled grains might be due to inadequate translocation of assimilates, ion imbalance, nutrient deficiency, and oxidative stress associated with saline conditions (Sadak *et al*. 2012). According to Mahmood *et al.* (2009) who reported that the higher salinity stress drastically decreased grain filling capacity, which in turn reduced grain yield. Reduced translocation of soluble carbohydrates to superior and inferior spikelets, increased sodium (Na+) and decreased potassium (K+) accumulation in all floral parts of the spikelet, and a decrease in starch synthesis in rice grains, which is essential for grain development were the causes of spikelet sterility and a decrease in seed setting rate (Hasanuzzaman *et al. 2*019). Literature has reported that the reduction in seed set in the panicle and it was attributed to decreased pollen viability, decreased receptivity of the stigmatic surface, or a combination of both factors (Khatun and Flowers 1995). Several spikelets on the lower primary branches do not mature into grains, potentially have a negative impact on both grain number and yield. The negative impacts of high salinity were mitigated through hormone treatment, focusing on revitalizing sink potential and enhancing the rate or duration of dry mass accumulation in developing reproductive organs. In the present study, foliar spray of consortia (T7) at different stages recorded the highest number of filled grains per panicle (112.93) and spikelet fertility percentage (80.54) and were 62.7 and 16.3 % more than that of control (T8) and were shown in table.2 and figure 2. Chen *et al.* (2022), Imran *et al.* (2023) and Okasha (2018) also reported that exogenous application of signal molecules increased the filled grains percentage under abiotic stress conditions.

**Table.1. Influence of Signal molecules on plant height and number of tillers in rice under salinity stress**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Plant Height (cm)** | | | | **Number of Tillers per plant** | | | |
| **Maximum tillering stage** | **Panicle initiation stage** | **Anthesis stage** | **Physiological maturity Stage** | **Maximum tillering stage** | **Panicle initiation stage** | **Anthesis stage** | **Physiological maturity Stage** |
| **T1** | 69.45 | 85.47\* | 91.88\* | 92.17\* | 12.18 | 15.13\* | 15.67\* | 16.00\* |
| **T2** | 62.18 | 81.12\* | 85.01\* | 85.37 | 9.53 | 11.52\* | 12.13\* | 12.71 |
| **T3** | 62.43 | 82.99\* | 86.37\* | 87.19 | 9.47 | 11.00 | 12.00 | 12.40 |
| **T4** | 63.73 | 83. 17\* | 87.52\* | 88.30\* | 9.64 | 11.71\* | 12.20\* | 12.80 |
| **T5** | 64.77 | 83. 53\* | 88.53\* | 89.52\* | 9.67 | 12.04\* | 12.40\* | 13.00\* |
| **T6** | 60.40 | 84.67\* | 89.16\* | 89.69\* | 9.80 | 12.58\* | 12.67\* | 13.27\* |
| **T7** | 66.25 | 85.09\* | 89.71\* | 90.08\* | 10.13 | 13.33\* | 13.67\* | 14.00\* |
| **T8** | 64.17 | 77.29 | 81.47 | 83.15 | 9.00 | 9.64 | 10.07 | 10.93 |
| **SE.m±** | **0.75** | **0.53** | **0.78** | **1.46** | **0.49** | **0.61** | **0.67** | **0.68** |
| **CD (p= 0.05)** | **2.27** | **1.62** | **2.35** | **4.42** | **1.48** | **1.85** | **2.03** | **2.05** |
| **CV (%)** | **2.02** | **1.11** | **1.54** | **2.86** | **8.52** | **8.76** | **9.20** | **8.90** |

|  |  |  |  |
| --- | --- | --- | --- |
| T1 | | : MCM 103 - A salt tolerant variety (Check) | SNP: Sodium Nitro prusside |
| T2 - T8 | | : BPT 5204 - A salt sensitive variety | SA : Salicylic Acid |
| \* | : Significant at 5% level | | BR : Brassinosteroids |

103 (maximum plant height by 10.6, 12.8 and 9.9 % over control -T1) at panicle initiation, anthesis and physiological maturity stages respectively. The above results were supported by the studies of Hussain *et al. 2*023 in rice, Escobar *et al*. (2010) in maize and Pai & Sharma (2023) who stated that the exogenous application of brassinosteroids, sodium nitro prusside, as nitric oxide (NO) donor and salicylic acid had a positive significant effect on plant height under salinity stress. Brassinosteroids can interact with endogenous auxin synergistically, results in cell elongation and cell proliferation of meristematic tissue (Sairam 1994).

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**3.4 Grain yield**

Soil salinity has a significant impact on several components that contribute to grain quality and yield (Khatun *et al*., 1995). Grain yield is determined by the ability of the source to furnish assimilates during the ripening period and the capacity of the sink to accumulate the translocated assimilates (Emongor *et al*., 2007). In the present study, grain yield was drastically decreased in the salt susceptible, BPT 5204 compared to the salt tolerant, MCM 103 variety under salinity stress. The similar results have shown by Prodjinoto *et al*. (2023) and Li *et al*. (2023). Further, the plant growth hormones played a positive role in increasing yield. Among different foliar application treatments, the foliar spray of consortia (T7- 5727.50 kg/ha) recorded the highest grain yield, followed by T6 (5655.42 kg/ha), and T5 (5644.36 kg/ha), also which were on par with MCM 103, salt tolerant variety (T1- 6189.89 kg/ha). The foliar spray of T7, T6 and T5 increased the grain yield by 20.8, 19.3 and 19.1 % over the control (T8), respectively. The studies of Jangid *et al*. (2017) and Dabariya and Bagdi, (2019) concluded that the exogenous application of brassinolide increased the grain yield by mitigating the salt stress effectively in wheat and barley, respectively. The application of salicylic acid through seed priming and foliar spray had a positive impact on grain yield under salt stress (Okasha, 2018). The above findings are in accordance with the results of the present study and it can be concluded that plant growth regulators, as a signal molecule could serve as valuable tools in enhancing grain yield.

**3.5 Straw yield and Harvest index**

The present study showed the results that the salinity stress reduced the straw yield, biological yield and harvest index reduced in the susceptible variety BPT 5204 more than that of salt tolerant MCM 103. Jahan *et al.* (2023) stated that straw yield decreased with increasing salinity levels in rice crop. All foliar treatments recorded significantly higher straw yield and on par with MCM 103 (T1- 6894.54 Kg/ha), except the foliar spray of T3. Among them, foliar spray of consortia (T7) was noticed with highest straw yield of 6508.49 kg/ha and it was 15.9% more than that of control (T8) and no significant influence was observed in HI. Hanif *et al*. (2024) observed a decrease in the straw yield and harvest index in Barley under salinity stress, while the exogenous application of salicylic acid improved those characters compared to control plants. The alleviating effect of foliar applied SA on harvest index was observed in *Salvia officinalis L.* and faba bean (Es-sbihi *et al*., 2021 and Hafez *et al*., 2021). It is an evident that the Plant growth regulators increased harvest index by maintaining proper photo- assimilate partitioning under stress conditions.

**3.6 Head Rice Recovery Percent and broken kernel percent**

In our study, the salinity stress degraded the quality of grains, in particular it reduced the head rice percent in susceptible variety, BPT 5204 more than that of the salt tolerant variety, MCM 103. It was observed that among different foliar applications, foliar spray of consortia treatment (T7) increased head rice rate (61.20%) by 24.62 % and decreased broken kernel percent (11.67%) by 211.5% over the control (T8), followed by T6, T5 and were on par with the salt tolerant MCM 103 (T1). The present study is consistent with the results of Yao *et al.* (2022) and Li *et al.* (2023) who stated that the percentage of head milled rice decreased significantly under the increasing salinity level. Pan *et al.* (2013) noted that head rice rate has positive impact when plant growth regulators applied externally in super hybrid rice. Yang *et al.* (2021) and Tang *et al*. (2022) reported that the exogenous application of plant growth regulators increased head rice recovery percent under high temperature stress and all these findings are in agreement with the results of our investigation.

**Figure 1: Percentage increase of foliar application treatments over the control treatment (**T8**) in plant height and number of tillers per plant under salinity stress in rice crop**

**Figure 2: Percentage increase of foliar application treatments over the control treatment (**T8**) on yield traits and quality character under salinity stress in rice crop**

**Table.2. Influence of Signal molecules on the Number of spikelets per panicle, Number of filled grains per panicle, Spikelet Fertility (%), Panicle length, Test Weight, grain and straw yield and Harvest index in rice under salinity stress**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Spikelet Fertility (%)** | **Grain yield (kg/ha)** | **Straw Yield (kg/ha)** | **Harvest Index (%)** | **Head rice recovery (%)** | **Broken kernel (%)** |
| **T1** | 85.36\* | 6189.89\* | 6894.54\* | 0.47 | 66.22\* | 11.04\* |
| **T2** | 77.26\* | 5441.42\* | 6364.24\* | 0.46 | 58.64\* | 12.93\* |
| **T3** | 76.42\* | 5482.97\* | 6302.61\* | 0.47 | 53.19 | 13.29 |
| **T4** | 78.18\* | 5553.08\* | 6376.77\* | 0.47 | 58.86\* | 12.71\* |
| **T5** | 79.93\* | 5644.36\* | 6434.38\* | 0.47 | 59.81\* | 12.32\* |
| **T6** | 80.02\* | 5655.42\* | 6431.83\* | 0.46 | 59.98\* | 11.99\* |
| **T7** | 80.54\* | 5727.50\* | 6508.49\* | 0.46 | 61.20\* | 11.67\* |
| **T8** | 69.24 | 4739.50 | 5614.56 | 0.46 | 49.11 | 14.86 |
| **SE.m±** | **2.26** | **218.64** | **175.50** | **NS** | **2.27** | **0.52** |
| **CD (p = 0.05)** | **6.84** | **663.07** | **532.13** | **6.88** | **1.58** |
| **CV (%)** | **4.99** | **6.82** | **4.80** | **6.73** | **7.23** |

|  |  |  |
| --- | --- | --- |
| **T1** | : MCM 103 - A salt tolerant variety (Check) | **SNP**: Sodium Nitro prusside |
| **T2 - T8** | : BPT 5204 - A salt sensitive variety | **SA** : Salicylic Acid |
| **\*** | : Significant at 5% level | **BR** : Brassinosteroids |

4. Conclusion

The current investigation on the effect of salinity stress on growth and yield aspects in two varieties revealed that salinity stress had a negative impact on these traits and ultimately has an impact on reduction of per hectare yield in the susceptible variety, BPT 5204. It was demonstrated through this study that there was considerable variation in responses to the foliar application of signal molecules on BPT 5204 at two growth stages *i.e.,* before and after reproductive stages. The best foliar spray combination to mitigate salinity stress was found to be 0.25 mM/L Sodium nitro prusside + 0.50 mM/L Salicylic acid + 0.50 mM/L Brassinosteroids. This combination increased plant height, number of tillers per plant, improved yield attributes and yield, and also enhanced grain quality under salinity stress. From this study, it can be concluded that the foliar application of 0.25 mM/L of Sodium nitro prusside + 0.50 mM/L of Salicylic acid + 0.50 mM/L of Brassinosteroids at before and after reproductive stages can alleviate the deleterious effects of salinity stress and it can be recommended safely for coastal areas, where soil salinity level is around 4 dSm-1.

References

 Ali Q, Daud M, Haider M Z, Ali S, Rizwan M, Aslam N, Noman A, Iqbal N, Shahzad F, Deeba F, *et al*. 2017. Seed priming by sodium nitroprusside improves salt tolerance in wheat (Triticum aestivum L.) by enhancing physiological and biochemical parameters. *Plant physiology and biochemistry***119**: 50–58. <https://doi.org/10.1016/j.plaphy.2017.08.010>

Bhowmik U, Kibria M G, Rhaman Ma S, Murata Y, & Hoque M A. 2021. Screening of rice genotypes for salt tolerance by physiological and biochemical characters. Plant Science Today **8**(3): 467–472. <https://doi.org/10.14719/pst.2021.8.3.1098>

Chen G, Zheng D, Feng N, Zhou H, Mu D, Zhao L, Shen X, Rao G, Meng F, & Huang A. 2022. Physiological mechanisms of ABA-induced salinity tolerance in leaves and roots of rice. Scientific Reports **12**. <https://doi.org/10.1038/s41598-022-11408-0>

Dabariya S & Bagdi D L. 2019. Impact of brassinolide in amelioration of salinity induced adverse effects on growth, yield attributes and yield of barley. *Journal of Pharmacognosy and Phytochemistry* **8**(6). 1536-1539.

Debez A, Chaibi W & Bouzid S. 2001. Effect of NaCl and growth regulators on germination of *Atriplex halimus* L. Cahiers Agricultures **10**.

Dolatabadian A, Modarres Sanavy S A M and Sharifi M. 2009. Effect of salicylic acid and salt on wheat seed germination. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science***59**:456–464. <https://doi.org/10.1080/09064710802342350>

Dramalis C, Katsantonis D & Koutroubas S D. 2021. Rice growth, assimilate translocation, and grain quality in response to salinity under Mediterranean conditions. AIMS Agriculture and Food **6**(1): 255–272. [10.3934/agrfood.2021017](http://dx.doi.org/10.3934/agrfood.2021017" \t "_blank)

Emongor V. 2007. Gibberellic Acid (GA3) influence on vegetative growth, nodulation and yield of cowpea (*Vigna unguiculata* (L.) Walp. *Journal of Agronomy* 6: 509-517. [https://scialert.net/abstract/?doi=ja.2007.509.517](https://scialert.net/abstract/?doi=ja.2007.509.517" \t "_blank)

Escobar H, Bustos R, Fernandez F E, Carcamo H J, Silva H, Frank N & Cardemil L. 2010. Mitigating effect of salicylic acid and nitrate on water relations and osmotic adjustment in maize, cv. *Lluteno* exposed to salinity. Ciencia e Investigacion Agraria **37**: 71-81. <https://doi.org/10.4067/S0718-16202010000300006>

Fahad S, Hussain S, Matloob A, Khan F A, Khaliq A, Saud S, Hassan S, Shan D, Khan F, Ullah N, *et al.* 2015. Phytohormones and plant responses to salinity stress: *A review. Plant Growth Regulation***75**: 391–404. <https://doi.org/10.1007/s10725-014-0013-y>

Es-sbihi F Z, Hazzoumi Z, Aasfar A, Amrani Joutei K. 2021. Improving salinity tolerance in *Salvia officinalis* L. by foliar application of salicylic acid. *Chem Biol Technol Agric*, **8**, 1–12. <https://doi.org/10.1186/s40538-021-00221-y>

Gao J P, Chao D Y and Lin H X. 2007. Understanding abiotic stress tolerance mechanisms: recent studies on stress response in rice. *Journal of Integrated Plant Biology* **49**: 742- 750. <https://doi.org/10.1111/j.1744-7909.2007.00495.x>

Habib N, Akram M S, Javed M T, Azeem M, Ali Q, Shaheen H L, Shaheen H L & Ashraf M. 2016. Nitric oxide regulated improvement in growth and yield of rice plants grown under salinity stress: Antioxidant defense system. Applied Ecology and Environmental Research **14**: 91-105. <http://dx.doi.org/10.15666/aeer/1405_091105>

Hafez E M, Osman H S, El-Razek U A A, Elbagory M, Omara AE-D, Eid M A, Gowayed S M. 2021. Foliar-applied potassium silicate coupled with plant growthpromoting rhizobacteria improves growth, physiology, nutrient uptake and productivity of faba bean (*Vicia faba L*.) irrigated with saline water in saltaffected soil. *Plants* **10**(5): 894. <https://doi.org/10.3390/plants10050894>

Hanif S, Mahmood A, Javed T *et al.* 2024. Exogenous application of salicylic acid ameliorates salinity stress in barley (*Hordeum vulgare* L.). *BMC Plant Biology* **24**, 270. <https://doi.org/10.1186/s12870-024-04968-y>

Haq T U, Akhtar J, Nawaz S & Ahmad R. 2009. Morpho-physiological response of rice (*Oryza sativa L*.) varieties to salinity stress. *Pakistan Journal of Botany* **41**(6): 2943-2956.

Harris D, Tripathi R S and Joshi A. 2002. On-farm seed priming to improve crop establishment and yield in dry direct-seeded rice In: Direct seeding: *Research strategies and opportunities,* 231-240. Pandey, S, Mortimer, M, Wade, L, Tuong, T. P, Lopes, K and Hardy B (Eds). International Rice Research Institute, Philippines.

Hasanuzzaman M, Alhaithloul H A S, Parvin K, Bhuyan M H M B, Tanveer M, Mohsin S M, Nahar K, Soliman M H, Al Mahmud J and Fujita M. 2019. Polyamine action under metal/metalloid stress: Regulation of biosynthesis, metabolism, and molecular interactions. *International Journal of Molecular Sciences* **20**: 3215. <https://doi.org/10.3390/ijms20133215>

Hasanuzzaman M, Fujita M, Islam M N, Ahamed K U & Nahar K. 2009. Performance of four irrigated rice varieties under different levels of salinity stress. International Journal of Integrative Biology **6**: 85-90.

Hayat S, Hasan S A, Yusuf M, Hayat Q and Ahmad A. 2010. Effect of 28 homobrassinolide on photosynthesis, fluorescence and antioxidant system in the presence or absence of salinity and temperature in *Vigna radiata*. *Environmental and Experimental Botany* **69**: 105-112. [https://doi.org/10.1016/j.envexpbot.2010.03.004](https://doi.org/10.1016/j.envexpbot.2010.03.004" \t "_blank" \o "Persistent link using digital object identifier)

Hussain S, Nanda S, Ashraf M, Siddiqui A R, Masood S, Khaskheli M A, Suleman M, Zhu L, Zhu C, Cao X, Kong Y, Jin Q & Zhang J. 2023. *Interplay Impact of Exogenous Application of Abscisic Acid (ABA) and Brassinosteroids (BRs) in Rice Growth, Physiology, and Resistance under Sodium Chloride Stress.* Life (Basel, Switzerland). **13**(2): 498. <https://doi.org/10.3390/life13020498>

Imran M, Hussain S, Iqbal A, et al. 2023. Nitric oxide confers cadmium tolerance in fragrant rice by modulating physio-biochemical processes, yield attributes, and grain quality traits. *Ecotoxicology and Environmental Safety* 115078. [https://doi.org/10.1016/j.ecoenv.2023.115078](https://doi.org/10.1016/j.ecoenv.2023.115078" \t "_blank" \o "Persistent link using digital object identifier)

Islam M Z, Baset Mia M A, Islam M R, & Akter A. 2007. Effect of Different Saline Levels on Growth and Yield Attributes of Mutant Rice. *Journal of Soil and Nature* **1**(2): 18-22.

Jangid K, Kanwar K, Panwar P, Asiwal RC, Bajya M and Bagdi D L. 2017. Effect of Brassinolide in amelioration of salinity adverse effects on growth and yield of wheat. *Journal of Pharmacognosy and Phytochemistry***6**(3): 194-197.

Jini D and Joseph B. 2017. Physiological Mechanism of Salicylic Acid for Alleviation of Salt Stress in Rice. *Rice Science* **24**(2): 97−108. [10.1016/j.rsci.2016.07.007](http://dx.doi.org/10.1016%2Fj.rsci.2016.07.007)

Khatun S and Flowers T J. 1995. Effects of salinity on seed set in rice. *Plant, Cell & Environment* **18**:61-67. [10.1111/j.1365-30401995.tb00544.x](http://dx.doi.org/10.1111/j.1365-3040.1995.tb00544.x" \t "_blank)

Khatun S, Rizzo C A and Flowers T J. 1995. Genotypic variation in the effect of salinity on fertility in rice. *Plant Soil* **173**: 239-250. <https://doi.org/10.1007/BF00011461>

Kibria, M.G, Hossain, M, Murata, Y, & Hoque, M.A. 2017. Antioxidant Defense Mechanisms of Salinity Tolerance in Rice Genotypes. Rice Science **24**: 155-162. [https://doi.org/10.1016/j.rsci.2017.05.001](https://doi.org/10.1016/j.rsci.2017.05.001" \t "_blank" \o "Persistent link using digital object identifier)

Li Z, Zhou T, Zhu K, Wang W, Zhang W, Zhang H, Liu L, Zhang Z, Wang Z, Wang B, Xu D, Gu J & Yang J. 2023. *Effects of Salt Stress on Grain Yield and Quality Parameters in Rice Cultivars with Differing Salt Tolerance*. Plants (Basel, Switzerland). **12**(18): 3243. <https://doi.org/10.3390/plants12183243>

Lutts S, Kinet J M and Bouharmont J. 1995. Changes in plant response to NaCl during development of rice (*Oryza sativa L*.) varieties differing in salinity resistance. *Journal of Experimental Botany* **46**(12): 1843-1852. <https://doi.org/10.1093/jxb/46.12.1843>

Ma H, Chong K and Deng X W. 2007. Rice research: Past, present and future. *Journal of Integrated Plant Biology* **49**: 729–730. <https://doi.org/10.1111/j.1744-7909.2007.00515.x>

Mahmood A, Latif T and Khan A M. 2009. Effect of salinity on growth, yield and yield components in Basmati rice germplasm. *Pakistan Journal of Botany* **41**(6):3035-3045.

Mantri N, Patade V, Penna S, Ford R and Pang E. 2012. *Abiotic stress responses in plants: present and future, in Abiotic Stress Responses in Plants: Metabolism, Productivity and Sustainability*, 1–19. P. Ahmad and M. N. V. Prasad (Eds). New York: Springer. <https://doi.org/10.1007/978-1-4614-0634-1_1>

Negacz K, Malek Z, Vos A D and Vellinga P. 2022. Saline soils worldwide: Identifying the most promising areas for saline agriculture. *Journal of Arid Environments* 203: 104775. [https://doi.org/10.1016/j.jaridenv.2022.104775](https://doi.org/10.1016/j.jaridenv.2022.104775" \t "_blank" \o "Persistent link using digital object identifier)

Okasha A M. 2018. Role of seed priming and spraying some bio and chemical substances in raising rice salinity tolerance and productivity. *Menoufia Journal of Plant Production* **3**(3): 269-286. [10.21608/mjppf.2018.175451](https://dx.doi.org/10.21608/mjppf.2018.175451)

Pai R & Sharma P K. 2023. Exogenous application of salicylic acid mitigates salt stress in rice seedlings by regulating plant water status and preventing oxidative damage. *Environmental and Experimental Biology* **20**(4): 193–204. <https://doi.org/10.22364/eeb.20.18>

Pan S, Rasul F, Li W, Tian H, Mo Z, Duan M and Tang X*.* 2013. Roles of plant growth regulators on yield, grain qualities and antioxidant enzyme activities in super hybrid rice (*Oryza sativa* L.). *Rice* **6**: 9. <https://doi.org/10.1186/1939-8433-6-9>

Panse V G and Sukhatme P V. 1978. *Statistical Methods for Agricultural Workers.* ICAR. New Delhi. 199-211.

Prodjinoto H, Gandonou C, Irakoze W & Lutts S. 2023. Impact of salinity on yield-related parameters in two contrasting cultivars of *Oryza glaberrima* Steud. In Benin. *In: Experimental Agriculture* **59** (59): 11. [https://doi.org/10.1017/S0014479723000030](https://doi.org/10.1017/S0014479723000030" \t "_blank)

Sadak M S, Abd El-Monem A A, El-Bassiouny H M S and Badr N M. (2012). Physiological response of sunflower (*Helianthus annuus* L.) to exogenous arginine and putrescine treatments under salinity Stress. *The Journal of Applied Sciences Research* **8**: 4943–4957.

Sairam R K. 1994. Effects of homobrassinolide application on plant metabolism and grain yield under irrigated and moisture-stress conditions of two wheat varieties. *Plant Growth Regulation* **14**(2): 173-181. <https://doi.org/10.1007/BF00025220>

Shalhevet J, Huck M G and Schroeder B P. 1995. Root and shoot growth responses to salinity in maize and soybean. *Agronomy Journal* **87**(3): 512-6.

Sharma R C, Rao B R M & Saxena R K. 2004. Salt affected soils in India-Current Assessment in advances in sodic land reclamation. *International Conference on sustainable Management of sodic Lands,* pp 1-26. Lucknow, India.

Singh R K, Redona E and Refuerzo L. 2009. Varietal improvement for abiotic stress tolerance in crop plants: special reference to salinity in rice. In: Abiotic stress adaptation in plants. *Springer, Dordrecht* 387–415. [10.1007/978-90-481-3112-9\_18](http://dx.doi.org/10.1007/978-90-481-3112-9_18" \t "_blank)

Statista. 2024. Rice - statistics & facts, Statista. [https://www.statista.com/topics/1443/rice/#topicOverview](https://www.statista.com/topics/1443/rice/" \l "topicOverview)

Tang S, Zhao Y, Ran X, Guo H, Yin T, Shen Y, Liu W and Ding Y. 2022. Exogenous Application of Methyl Jasmonate at the Booting Stage Improves Rice’s Heat Tolerance by Enhancing Antioxidant and Photosynthetic Activities. *Agronomy* **12**: 1573. <https://doi.org/10.3390/agronomy12071573>

USDA. 2024. Production- Rice, U.S. Department of Agriculture Foreign Agricultural Service. <https://fas.usda.gov/data/production/commodity/0422110>

World Soil Day: FAO highlights the threat of soil salinization to global food security <https://www.fao.org/global-soil-partnership/resources/highlights/detail/en/c/1458974/>.

Xu Y, Bu W, Xu Y, Fei H, Zhu Y, Ahmad I, Nimir N E A, Zhou G and Zhu G. 2024. Effects of Salt Stress on Physiological and Agronomic Traits of Rice Genotypes with Contrasting Salt Tolerance. Plants **13**(8):1157.  <https://doi.org/10.3390/plants13081157>

Yang J, Duan L, He H, Li Y, Li X, Liu D, Wang J, Jin G & Huang S. 2021. Application of Exogenous KH2PO4 and Salicylic Acid and Optimization of the Sowing Date Enhance Rice Yield Under High-Temperature Conditions. *Journal of Plant Growth Regulation* **41**(4): 1532-1546. <https://doi.org/10.1007/s00344-021-10399-y>

Yao D, Wu J, Luo Q, Zhang D, Zhuang W, Xiao G, Deng Q and Bai B. 2022. Effects of Salinity Stress at Reproductive Growth Stage on Rice (*Oryza sativa* L.) Composition, Starch Structure, and Physicochemical Properties. *Frontiers in Nutrition* **9**: 926217. <https://doi.org/10.3389/fnut.2022.926217>

Zeng L & Shannon M C. 2000. Salinity effects on rice seedlings and yield components. *Crop Science* **40**(4): 996-1003.  <https://doi.org/10.2135/cropsci2000.404996x>