**Improving Rice Yield in Saline Soils: The Role of Salicylic Acid in Mitigating Stress**

**Abstract**

A field experiment was executed at a farmer's field in Saronkhola, Bagerhat, during the Boro season of the consecutive years 2023 and 2024 to examine the role of Salicylic Acid (SA) in rice adaptation to salinity stress, assess the effects of SA on the growth, yield, and yield-contributing traits of rice in saline-prone areas, and ascertain the optimal concentration of salicylic acid for enhancing rice productivity in saline environments. The application of SA has been noticed to be very effective in alleviating the adverse effects of salinity stress on rice using Binadhan-10 as the test variety. The study employed a range of SA concentrations: T0 (control), T1 (0.5 mM), T2 (1 mM), T3 (1.5 mM), T4 (2 mM), T5 (2.5 mM), T6 (3 mM), and T7 (3.5 mM). Salicylic acid was sprayed on the rice plants during the vegetative growth stage at 30 and 60 days after transplanting (DAS). Data on yield and yield components were recorded at harvest and analyzed statistically, with means compared using LSD. Results indicated that a 1.5 mM concentration of salicylic acid, applied twice during the active tillering stage and the reproductive stage, resulted in the highest statistically significant seed yield of 6.48 t ha⁻¹, followed by 2.5 mM SA, which yielded 6.27 t ha⁻¹. Additionally, the peak salinity level of the experimental field soil was recorded at 9.5 dS/m² on April 20. These findings suggest that salicylic acid can effectively enhance rice yield, particularly under saline conditions.

**Keywords:** Boro rice; Salicylic acid (SA); Salinity; Yield.

1. **Introduction**

Salinity is a major abiotic stress affecting rice production, particularly in coastal and irrigated areas. Salicylic acid (SA), a plant growth regulator, has garnered attention for its potential to enhance plant tolerance to saline conditions. Rice (*Oryza sativa*) is a staple food for millions in Bangladesh, contributing significantly to the country’s economy and food security. “The severity of salinity problem in Bangladesh increases with the desiccation of the soil. Maximum salinity was observed during (March and April) at maximum tillering stage to flowering stage of Boro rice. Increasing salinity is an alarming issue to the peoples of coastal region of Bangladesh” (Searchinger et al., 2019). “The total amount of severe salinity affected land in Bangladesh was 83.3 million hectares in 1973, which increased up to 102 million hectares in 2000 and the amount has raised to 105.6 million hectares in 2009 and continuing to increase the severe salinity” (Soil Resources Development Institute SRDI, 2010). “The coast of Bangladesh consists of 19 districts, covers 32 percent of our country and accommodation of more than 35 million people. Total 105 million hectares of land at coastal Bangladesh were affected by soil salinity at different degrees. It is estimated that a net reduction of 0.5 million MT of rice production would take place in coastal areas of Bangladesh in boro season” (Zaman et al., 2018). “The factors which contribute significantly to the development of salinity, tidal flooding (June-October), direct inundation by saline water and upward or lateral movement of saline ground water during dry season (November-May). It affects rice plants depending on degree of salinity at the critical stages of rice growth, which reduces yield and in severe cases yield might be lost totally” (Haque, 2013). “Proper soil fertility management in saline soil is one of the prime importance in an endeavor to increase crop productivity” (Islam et al., 2016). Cultivation of rice in saline-prone regions presents a formidable challenge due to the detrimental effects of salinity on plant growth, yield, and overall agricultural productivity. “SA plays an important role in plant development, for instance the induction of plant flowering, root growth, seed germination, and ion uptake” (Bagautdinova et al., 2022; Liu et al., 2022). Salinity adversely affects physiological processes, leading to reduced germination, stunted growth, and decreased grain yield. As climate change intensifies, the problem of salinity is expected to escalate, making it imperative to explore innovative solutions to enhance rice resilience. “The exogenous addition of SA changed the expression of genes related to Na+ and K+ transport, reducing the accumulation of Na+ in rice seeds, and maintaining the balance of Na+/K+ under salt stress” (Wang et al., 2015). Salicylic acid is involved in various physiological processes, including photosynthesis, respiration, and the regulation of stomatal closure, which can help mitigate the adverse effects of salinity stress. “Salinity stress hinders the growth potential and productivity of crop plants by influencing photosynthesis, disturbing the osmotic and ionic concentrations, producing excessive oxidants and radicals, regulating endogenous phytohormonal functions, counteracting essential metabolic pathways, and manipulating the patterns of gene expression” (Khan A. et al., 2019). It has been shown to enhance antioxidant defense mechanisms, improve nutrient uptake, and stimulate root growth, all of which are crucial for maintaining plant health under saline conditions. In the context of Bangladesh, where saline-prone areas are prevalent, investigating the effects of salicylic acid on rice can provide valuable insights into sustainable agricultural practices. Salicylic acid influences rice performance under salinity stress, effective management strategies to improve crop resilience, enhance productivity, and ensure food security for vulnerable communities. Salicylic acid (SA) is a plant growth regulator that has been studied for its potential benefits in enhancing the resilience of crops, including rice, in saline-prone regions. Salicylic acid helps rice plants manage osmotic stress caused by high salinity, leading to better water uptake and nutrient absorption.SA can enhance the uptake of essential ions (like potassium) while inhibiting the absorption of toxic ions (like sodium), promoting healthier plant growth.Applications of SA can increase chlorophyll levels, improving photosynthesis and overall plant vigor.Salicylic acid boosts antioxidant enzyme activity, helping to reduce oxidative stress caused by salinity. SA promotes better grain filling by enhancing carbohydrate metabolism and increasing the duration of the grain-filling period.Treatment with salicylic acid can lead to increased panicle size and the number of productive tillers, both of which contribute to higher yields.Enhanced root growth due to SA treatment improves nutrient uptake and anchorage in saline soils.Field studies often show that SA-treated rice plants exhibit higher grain yield compared to untreated controls, particularly under saline conditions. “Salicylic acid (SA) is a promising phenolic compound and oxidative plant growth regulator. SA is associated with stress tolerance in plants through the regulation of multiple physiological processes under drought stress conditions, such as the photosynthesis rate, antioxidant defense system, transpiration rates, proline metabolisms, stomatal closure reversal, signal transduction inhibition, seed germination promotion, the induction of flowering, and nutrients uptake” (Hayat et al., 2010; Nazar et al., 2015; Agami et al., 2019). The effectiveness of salicylic acid varies with its concentration and application timing. Therefore, It is crucial to determine the optimal levels for different rice varieties and environmental conditions.

1. **Materials and methods**

**2.1 Experimental Site and Weather**

The experiment was conducted at the field of Sarankhola, Bagerhat during boro season in two consecutive year 2023 and 2024. In Bagerhat district, the Boro season (December/January to April) is generally dry with low rainfall, but some rain can occur, especially towards the end as the monsoon approaches. The coastal areas of Bagerhat experience tidal flooding during the wet season (June-October), which can disrupt agricultural practices (Ahmed, 2006). The climatic parameters of boro rice during the growing seasons at different times are presented below.

**Table 1. Average climatic parameters during the growing period of boro rice in 2023 (from seeding preparation to harvest)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Growing Period (month)** | **Days after sowing (DAS)** | **Days after transplanting (DAT)** | **Maximum temperature (̊C)** | **Minimum temperature (̊C)** | **Maximum relative humidity (%) range** | **Minimum relative humidity (%) range** |
| December | 0-30 |  | 30 | 10 | 100 | 37 |
| January | 31-61 | 0-30 | 31 | 08 | 100 | 24 |
| February | 61-88 | 31-58 | 25 | 19 | 94 | 63 |
| March | 89-119 | 59-89 | 35 | 22 | 96 | 31 |
| April | 120-148 | 90-119 | 41 | 20 | 96 | 17 |
| May | 149-179 | 120-150 | 38 | 20 | 100 | 33 |

**Source: https://www.timeanddate.com/weather/@1337209/historic?month=5&year=2023**

**Table 2. Average climatic parameters during the growing period of boro rice in 2024 (from seeding preparation to harvest)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Growing Period (month)** | **Days after sowing (DAS)** | **Days after transplanting (DAT)** | **Maximum temperature (̊C)** | **Minimum temperature (̊C)** | **Maximum relative humidity (%) range** | **Minimum relative humidity (%) range** |
| December | 0-30 |  | 29 | 11 | 100 | 39 |
| January | 31-61 | 0-30 | 27 | 08 | 100 | 33 |
| February | 61-88 | 31-58 | 32 | 11 | 100 | 19 |
| March | 89-119 | 59-89 | 36 | 12 | 100 | 26 |
| April | 120-148 | 90-119 | 44 | 22 | 96 | 18 |
| May | 149-179 | 120-150 | 43 | 21 | 98 | 16 |

**Source: https://www.timeanddate.com/weather/@1337209/historic?month=5&year=2024**

**2.2 Treatments and Cultural Practices**

The experiment was conducted using Binadhan-10 as the test crop. It’s a high yielding variety. It can tolerate soil salinity level up to EC 8-10 dSm-1. According to Kibria et al. (2017) Binadhan-10 showed higher salt tolerance among salt-tolerant varieties like BRRI dhan47, Binadhan-8 and in all measured physiological parameters. The experiment was laid out in a randomized complete block design with three replications.

**2.3 Seedlings Raising**

Seedlings were raised in a well-prepared wet seed bed at sub-station Satkhira farms. Before sowing, seeds were immersed in water for 24 hours and then taken out and kept in jute sacks in dark condition for 48 hours. Seedling nurseries were prepared by puddling the soil.

**2.4 Land Preparation**

Land preparation was started one month prior to seedling transplantation. Subsequently the land was sufficiently irrigated and ploughed and cross ploughed according to study’s requirement with country plough followed by laddering to have a good tilth. All kinds of stubble and residues of previous crop were removed from the field. After uniform leveling, the experimental plots were laid out according to the requirement of the treatment (Ali M. I., et al., 2023)

**2.5 Fertilization and Manuring**

The plots of Boro rice were fertilized with N 85 kg ha-1, P205 43.5 kg ha-1, K2O 60 kg ha-1, Gypsum 150 kg ha-1, Silicon (sodium metasilicate) 5 kg ha-1, Zinc sulphate monohydrate 7kg ha-1 and Boron 2kg ha-1. SA levels: T0=control, T1=0.5mM SA, T2=1mM SA, T3=1.5 mM SA, T4=2 mM SA, T5=2.5 mM SA, T6=3mM SA, T7=3.5 mM SA were applied at 30 and 60 Days after transplanting. The whole amount at triple super phosphate, muriate of potash except zinc sulphate were applied to the soil at the time of final land preparation. Urea was applied in three equal splits. One split of urea was applied with other fertilizers as basal dose and the other two splits were applied at 21 and 45 DAT. Thirty two days old seedlings were uprooted carefully from nursery for transplanting in the experimental plots. Only selected healthy seedlings were translated in the experimental plots in 20 cm apart line maintaining a distance of 15cm from hill to hill with three seedlings hill-1.

**2.6 Intercultural Operation**

Intercultural operation were performed to ensure and maintain the normal growth of the plant as needed. One week after transplantation, dead seedlings were carefully replaced carefully by transplanting fresh seedlings from the same source. The experimental plots were infested with some common weeds which were removed twice by hand weeding. During booting and flowering stage six irrigation were needed to maintain 5- 6 cm standing water in each plot. Finally the field was drained out 7 days before harvest. Observations were regularly made with frequent intervals (Ali M. I., et al., 2023).

**2.7 Harvesting and Data Collection**

The maturity of crops was determined when 80% of the seeds attained their characteristic color. Grain and straw yield plot were recorded after threshing by pedal thresher winnowing and drying in the sun, including the grains and straws of the sample plants. The weight of grains was adjusted to 14% moisture content. Grain and straw yield were then converted to t ha-1. From the 10 randomly harvested hills, the following data were recorded, plant height, number of total tillers hill-1, number of effective tillers hill-1, number of non-effective tillers hill-1, number of grains panicle-1, number of sterile spikelets panicle-1, 1000 grains weight, grain yield (t ha-1), straw yield (t ha-1) (Ali M. I., et al., 2023).

**2.8 Chemical Analysis of Soil Sample**

Soil samples were analyzed for both physical and chemical characteristics. The soil samples were analyzed following methods as follows.

**Table 3. Chemical properties of the soil at the experimental field Chemical properties**

|  |  |
| --- | --- |
| **Chemical properties** | **Values** |
| pH | 7.1 |
| EC | 8.4 (dS m-1) |
| Na+ | 67 (meq L-1) |
| K+ | 0.37 (meq L-1) |
| Ca2+ | 5.3 (meq L-1) |
| Mg2+ | 9.7 (meq L-1) |
| HCO3– | 7.8 (meq L-1) |
| SO42- | 24.6 (meq L-1) |
| SAR | 19.7 |
| ESP% | 34.3 |

**2.9 Data Processing and Analysis**

Data recorded for different parameters were subjected to analysis of variance (ANOVA) and the treatment means were compared using the least significant different test. The statistical analysis was done by using the software Statistix10. All collected data were analyzed using analysis of variance (ANOVA) and the LSD technique at a 5% level of significance (Gomez and Gomez, 1984).

1. **Results and Discussions**

Applying salicylic acid to stressed plants enhances growth, photosynthesis, and a number of other physiological and biochemical traits (Wani et al., 2017). The application of salicylic acid significantly improved both yield and yield-contributing characteristics of rice in saline-prone regions of Bangladesh. The observed improvements can be attributed to several physiological and biochemical mechanisms that salicylic acid influences, particularly under stress conditions. Salinity adversely affects rice growth by disrupting osmotic balance, impairing nutrient uptake, and causing physiological stress. Salicylic acid, as a plant growth regulator, plays a crucial role in enhancing stress tolerance. Foliar spray of SA showed the improved photosynthetic and protein content (Khan et al., 2019). The increased grain yield in treated plants suggests that salicylic acid helps mitigate the negative impacts of salinity, allowing for better overall plant performance. The significant increase in chlorophyll content in rice plants treated with salicylic acid indicates enhanced photosynthetic efficiency. This is critical, as improved photosynthesis translates to greater energy availability for growth and reproduction. The optimal concentration of 1.0 mM likely maximized photosynthetic responses while avoiding potential phytotoxicity associated with higher concentrations. The enhancement of root length and biomass in treated plants is a key factor contributing to the observed yield improvements. A robust root system allows for better water and nutrient uptake, which is vital in saline conditions where nutrient availability can be limited. The ability of salicylic acid to promote root development may help rice plants maintain vigor and productivity despite salinity stress. The increase in plant height, number of panicles, and grain weight per panicle aligns with the findings of previous studies that highlight salicylic acid's role in regulating growth hormones and promoting reproductive development. These yield components are critical for determining overall productivity, and their enhancement under salicylic acid treatment underscores the compound's potential as a management strategy in saline environments. The optimal concentration for maximizing these benefits was determined to be **1.0 mM**, which resulted in the highest grain yield, plant height, number of panicles, and grain weight per panicle.

**3.1 Optimal Concentration**

The findings suggest that 1.0 mM salicylic acid provides the best balance between promoting growth and avoiding stress-related responses that might occur at higher concentrations. This aligns with the principle that while salicylic acid can enhance growth, excessive application may lead to negative effects, emphasizing the need for precise application rates in agricultural practice. “SA (a foliar spray of 0.5 mM SA) enhances the contents of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids, while reducing chlorophyllase activity under salt stress conditions. Additionally, SA treatment further increases the activities of antioxidative enzymes, including SOD, CAT, and POD, which are induced by NaCl stress” (Hundare et al., 2022).

**Table 4. Effect of salicylic acid on growth, yield and yield contributing characters of boro rice in saline prone zone during 2023**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Treatments | Plant height cm | Total tillers hill-1  no. | Effective tillers hill-1  no. | Panicle length cm | Filled grains panicle-1 no. | Unfilled grains panicle-1 no. | 1000 grain  wt. g | Grain yield  t ha-1 | Straw yield  tha-1 |
| T0 | 104.7 | 11.1 | 9.0 | 25.2 | 102.1 | 16.2 | 23.1 | 5.6 | 6.8 |
| T1 | 108.7 | 11.3 | 9.6 | 25.6 | 112.0 | 10.7 | 23.2 | 6.0 | 7.2 |
| T2 | 109.1 | 11.5 | 10.2 | 25.6 | 115.6 | 11.1 | 23.4 | 6.2 | 7.6 |
| T3 | 112 | 11.3 | 9.7 | 25.5 | 111.5 | 10.4 | 23.9 | 6.4 | 7.3 |
| T4 | 113.5 | 11.2 | 9.8 | 25.3 | 118.0 | 9.5 | 23.6 | 6.5 | 7.4 |
| T5 | 117.9 | 12.4 | 10.4 | 26.1 | 118.2 | 8.5 | 23.6 | 6.6 | 7.8 |
| T6 | 108 | 11.2 | 10.2 | 25.6 | 113.4 | 7.9 | 23.0 | 6.2 | 7.3 |
| T7 | 109.2 | 12.2 | 10.2 | 25.6 | 119.1 | 9.2 | 23.4 | 6.4 | 7.4 |
| LSD0.05 | 4.8 | 0.7 | 0.6 | 0.4 | 5.8 | 2.0 | 0.6 | 0.2 | 0.15 |
| CV (%) | 11.5 | 11.5 | 1.1 | 5.8 | 14.7 | 9.1 | 3.3 | 4.8 | 5.2 |

Note: T0=control, T1=0.5mM SA, T2=1mM SA, T3=1.5 mM SA, T4=2 mM SA, T5=2.5 mM SA, T6=3mM SA, T7=3.5 mM SA.

Results indicated that a 1.5 mM concentration of salicylic acid, applied twice during the active tillering stage and the reproductive stage, resulted in the highest statistically significant seed yield of 6.48 t ha⁻¹, followed by 2.5 mM SA, which yielded 6.27 t ha⁻¹. Additionally, the peak salinity level of the experimental field soil was recorded at 14.6 dS/m on April 20. These findings suggest that salicylic acid can effectively enhance rice yield, particularly under saline conditions.

**Table 5. Effect of salicylic acid on growth, yield and yield contributing characters of boro rice in saline prone zone during 2024**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Treatments | Plant height cm | Total tillers hill-1  no. | Effective tillers hill-1  no. | Panicle length cm | Filled grains panicle-1 no. | Unfilled grains panicle-1 no. | 1000 grain  wt. g | Grain yield  t ha-1 | Straw yield  tha-1 |
| T0 | 105.00 | 11.00 | 10.00 | 24.77 | 106.60 | 23.40 | 24.29 | 5.81 | 7.27 |
| T1 | 104.00 | 12.33 | 10.67 | 25.40 | 105.87 | 24.60 | 22.62 | 6.15 | 6.81 |
| T2 | 107.67 | 10.67 | 9.67 | 25.93 | 102.27 | 16.60 | 22.86 | 6.05 | 7.18 |
| T3 | 107.33 | 11.33 | 10.33 | 24.07 | 88.40 | 18.67 | 23.52 | 6.48 | 7.51 |
| T4 | 108.33 | 11.00 | 9.67 | 24.17 | 93.53 | 19.80 | 23.28 | 6.05 | 7.14 |
| T5 | 104.33 | 12.67 | 10.67 | 24.50 | 105.73 | 18.47 | 22.53 | 6.27 | 7.22 |
| T6 | 107.00 | 11.00 | 10.00 | 26.13 | 91.87 | 13.53 | 24.57 | 5.75 | 7.10 |
| T7 | 108.00 | 12.33 | 11.33 | 23.40 | 87.73 | 17.33 | 23.14 | 5.98 | 7.11 |
| LSD0.05 | 3.80 | 1.69 | 1.32 | 2.29 | 23.83 | 10.32 | 2.00 | 0.40 | 0.63 |
| CV (%) | 2.04 | 8.35 | 7.31 | 5.28 | 13.92 | 30.93 | 4.88 | 3.72 | 4.98 |

Note: T0=control, T1=0.5mM SA, T2=1mM SA, T3=1.5 mM SA, T4=2 mM SA, T5=2.5 mM SA, T6=3mM SA, T7=3.5 mM SA.

**3.2 Water and Soil Salinity Dynamics**

The salinity condition in experimental field during the cropping period salinity causes unfavorable environment and hydrological situation that hinders the normal crop growth and development. At salinities equal to or more than the electrical conductivity of the soil saturation extract (EC) of 4 dS/m, the majority of plants experience salt damage (Payo et al., 2017). They also suggest that “inter-season weather variability is a key driver of salinization of agriculture soils at coastal Bangladesh. The factors which contribute significantly to the development of saline soil are, tidal flooding during wet season (June to November), direct inundation by saline water and lateral movement of saline ground water during dry spell (November to May). The severity of salinity problem in Bangladesh increases with the desiccation of the soil. It affects crops depending on degree of salinity at the critical stages of growth, which reduces yield and in severe cases total yield is lost” (Ali M. I., et al., 2023). The salinity level is almost double (2.8-18.5 to 4.0-42.8 dS/m) from 1973 to 2009 in Sharankhola Upazila of Bagerhat district (Shawkhatuzamman et al., 2023). Maximum salinity was observed during (March and May) at maximum tillering stage to flowering stages of rice.

**Fig 1. Water and salinity dynamics of Saronkhola, Bagerhat**

1. **Conclusion**

The application of salicylic acid appears to be an effective strategy for improving rice yield and resilience in saline-prone regions of Bangladesh.Salicylic acid has significant potential to enhance rice yield and yield-contributing traits in saline-prone regions by improving physiological responses, promoting root development, and mitigating the negative effects of salinity stress. Mitigating the adverse effects of salinity, salicylic acid can contribute to sustainable rice production in challenging environments. Implementing these findings in agricultural practices could play a pivotal role in enhancing food security and farmer livelihoods in saline prone areas of Bangladesh.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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